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**AFONSO LEITE DA SILVA SIMÕES PAIÃO**

# DEVELOPMENT OF A FRAMEWORK FOR THE FLEXIBILITY MEASUREMENT OF INTRALOGISTIC SYSTEMS BASED ON A FUZZY LOGIC APPROACH

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Mecânica, realizada sob a orientação científica do Doutor Mustafa Güller, Professor do Departamento de Engenharia Mecânica da Technische Universität Dortmund

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# MASTERARBEIT

# Development of a Framework for the Flexibility Measurement of Intralogistic Systems based on a Fuzzy Logic approach

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# Chapter 1

# 1. Introduction

"Nowadays, having the best product/service is not enough to win in the worldwide market.". by Filipe de Button, Logoplaste CEO. In a world where everything is changing so fast, all of us have to be ready to react in the quickest and in the most efficient direction. For example, the weather is becoming more and more unpredictable, world civilian fights are becoming more frequent, trends in different products/services are becoming more intensive and common, environment situations are changing and it is occurring at a consistent everyday basis. Being capable of understanding what is surrounding us is a trump card. To achieve what is necessary, we must utilize pure knowledge, experience and willingness to always do more and improve. [Forslund & Jonsson, 2007 p. 94]

Until now, different papers and books have been written, but not one with the same approach as this work. Books and papers concerning the general and trendy term "Supply Chain Management" (SCM) are uncountable. [Ross, 1998 p. 1-26; Taylor, 1998 p. 28-29; Poirier, 1999 p. 1-11; Gunasekaran et al., 2001 p. 71-75] Focusing on one of the steps within the SCM, warehouse, becomes a more refined search but still relatively easy to find information about this topic. Concerning warehouse's efficiency there are still some works and papers about it. [De Koster et al., 2008 p. 5-8; Barry, et al. 2008 p.1-6; Ayodhiramanujan, 2009 p. 10-18; Johnson et al., 2010 p. 221] But in these works exists a lack of information when searching about warehouses evaluation. Focusing on warehouse flexibility principally, the warehouses are present in almost all the SCM stages, as it is possible to analyze in the Figure 1.1 below.

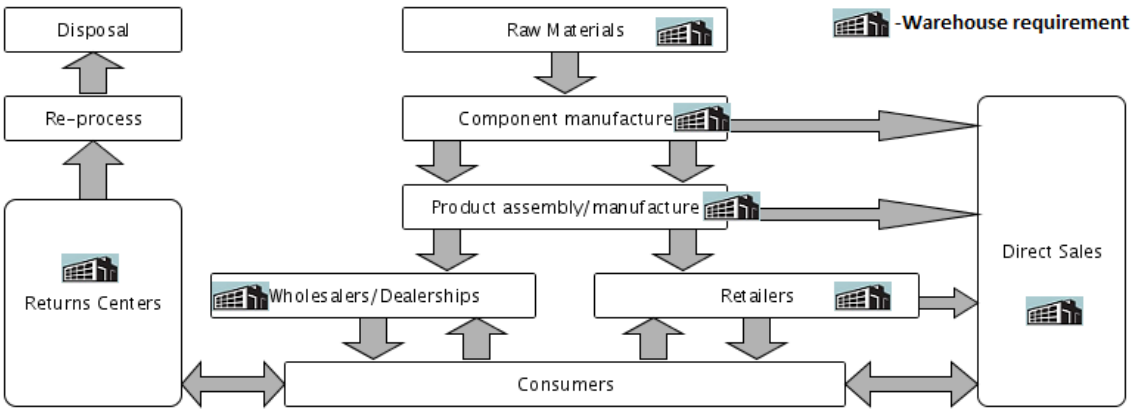


**Figure 1.1-Warehousing in the supply chain [Richards, 2011 p. 10]**

## 1.1 Warehouse Flexibility

Focusing on our theme, warehouse flexibility, there are so much things to refer and explain. To start, in a brief and concise way, flexibility is the capability of leading with the unexpected. [Brandenberg, web] Others say, that dealing with the unforeseen is already being prepared, and consequently it is not considered pure flexibility. Some authors defend that flexibility must be planned and managed. [Sethi et al., 1990 p. 295-296]

Accordingly, it is important to understand that the competence of dealing with unpredicted operations are considered to be flexible in this work. Even if there existed a previous plan, preparation or nothing. So a general and wide term of Flexibility was adopted, instead of a more meticulous and fancy designation. [Laczniak & Lusch, 1997 p. 60]

Considering Clarence Darrow with reference to Figure 1.2, "*It is not the strongest species that survive, nor the most intelligent, but the ones most responsive to change.*" In this way, the challenge starts regarding warehouse flexibility. Some authors, more in scientific papers than in books, wrote about warehouse flexibility systems, but in a vague and general approach. Gwyhnne Richards (2011), in his book "Warehouse Management - A complete guide to improving efficiency and minimizing costs in the modern warehouse" takes a really close look to the main theme of this thesis. In this book, Richards, gives us full information about important aspects related with warehouse flexibility. It is a recent source of information with actualized material turning out to be a good resource of help.

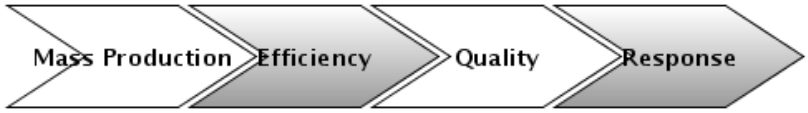


**Figure 1.2- Evolution of Production Systems [Taylor 2003, p. 12]**

A lack of data was found, after spending some time searching for more information and data related with flexibility warehouse. All the sources describe what is the warehouse's flexibility concept, but in a vague and superficial way. Most of them always focus on the general efficiency's term and then converging in a small sub-topic about flexibility, thus not about pure flexibility. Besides this, what was impossible was to find a procedure to evaluate the flexibility among the main warehouse steps. When facing complex systems, where big amounts of time and money are invested, it is normal the presence of data's analyses related with the results or performances of the system in question, for further analyses such as comparisons and improvements. [Bates et al., 1999 p. 115] But in this specific case, concerning warehouse's flexibility, they did not find any kind of systems that were capable of providing data to further analyses and assessment.

We discovered two different problems. The first, concerning lack of information about pure flexibility in the warehouse. Second, a simple and easy way to evaluate warehouse's flexibility.

## 1.2 Motivation for the Current Research

This work was undertaken to comprehend and fully analyze all the factors that contribute to the flexibility associated with the warehouse. As it was referred in the beginning of this introduction, what we can expect today is the unexpected tomorrow. Due to that, the warehouses nowadays, by some of us, are not being recognized as essential partners in all the chains. They have to search for improvements to help add value to the product, and not just adding costs to it. Some years ago, the majority of the people in the production business didn't could understand the value of the warehouses, nowadays it is completely different, due to the warehouse's improvements that are appearing every day. [Richards, 2011 p.7]

Now, warehouse systems are viewed as potential partners in a competitive market. At the same time with all the unexpected events that occur everyday it is extremely difficult to guess what is going to happen tomorrow. In a world where nothing can be taken for granted, everything is changing all the time. Having the capacity of holding stock and delivering goods as fast as possible is crucial. The warehouses are responsible to set the pace as the clients demand. [Faber et al., 2013 p. 1230]

To confirm that improvements and changes are really happening proofs have to be presented. As Tom Peters once said, "*What you do not measure, you cannot contro*l.", that is why the part of evaluation is fundamental. The evaluation brings the proof and the data that every company needs to keep moving forward, to have the capacity of being compared with others, to have ability of benchmarking with the bests in the segment, or just in the lowest level, to compare results from year to year within the company. [Jalalvand et al., 2011 p.82]

After going through a large number of different factors, it was possible to select just the ones that could somehow influence the flexibility. This turned out to be a delicate process, because it is difficult to impose a barrier between pure flexibility and efficiency, as it will be discussed later.

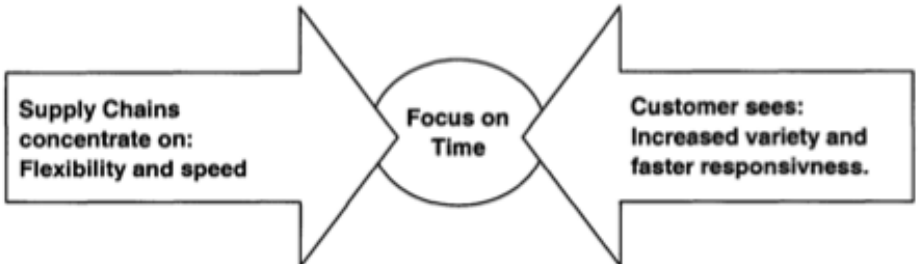


**Figure 1.3- Focus on Time [Taylor, p. 15]**

Putting together, side-by-side, all the selected factors that really represent the so desire flexibility in the warehouse, with a program capable of evaluating it, is what was missing. If you want to be the best, or even just to work within the company standards, you need to have data that classify how the work is being performed. This thesis brings the work capable of covering that lack of information and system. Speed and responsiveness (previously Figure 1.3) are what the customers are looking for together in the supply chain, with a reduction of costs. [Randall et al., 2003 p. 430]

## 1.3 Problem Statement

On the whole, this work was conceived to answer the emergence of developing a framework to measure the intralogistic warehouse's system flexibility, based on a fuzzy logic approach.

The motive to create a program using fuzzy logic software was because this new language is extraordinarily flexible. It is not a normal language of programming. With fuzzy logic it is possible to create different values between the ordinary binary system (0 and 1), which is common among all the programming languages. This characteristic provides a large variety of possibilities and results. [Krizsán et al., 2013 p. 1; The Math Works, 2014 p.1-3/1-7]

The range of this work for now is limited. It offers good help when trying to comprehend the practical factors that really matter to achieve flexible in the warehouse, and besides that, also a good help when entering in the world of fuzzy logic. Concerning the warehouse flexibility assessment, it is still short to evaluate a complex warehouse. Due to some reasons that will be explained during the work, for now, cannot fully assess the flexibility in a warehouse. In contrast to that, this work provides an optimal tool to analyze the potentiality of these kinds of systems. In a small scale it is possible to assess a warehouse without troubles. In these cases, this framework is capable of providing a warehouse grade regarding the flexibility parameter.

This work is also directly aimed to a warehouse's flexibility researchers that want to have an approximation to the possibility of assessment flexibility. It can also be useful for everyone who wants to develop a program based on fuzzy logic to later assess an intralogistic system. With further tuning and improvements, it will be capable of fully analyzing a flexibility warehouse system.

At this point of the work it is necessary to affirm, because it will happen through all the following work that efficiency is not flexibility. Sometimes they walk in the same direction, but other times they don't. Efficiency is not the aim of this work, yet will appear in some moments while trying to explain some particular situations.

## 1.4 Overview of the Document

The following work will be divided in two main parts: theoretical and practical part. The practical part will also contain some theory, but related with the pure practical work. In the next Figure 1.4 it is possible to analyze how the two different parts of the work come together.

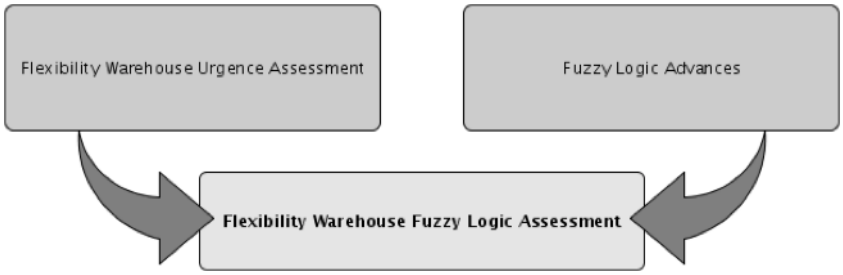


**Figure 1.4- Objective of the Work**

Related with the first part, the theoretical, it is to present a brief explanation about Supply Chain Management. Here it is possible to find concise information about production history and the actuality, also general characteristics to be successful in the production world and the emergence for flexibility in every kind of processes and systems. Correlated with SCM comes the intralogistic systems topic. This is described as the definition of this recent and modern term. Going further in the work, it is possible to find the first topic only related with warehouse theme. Types of warehouse operations are part of this matter, followed by the motivations of the importance of holding stock; these are the reasons for the warehouse's existence. They try to understand the difference between labor flexibility and machine flexibility, together with motivation and support by all the warehouse team, a closer look to the warehouse manager responsibilities will also be part of this work.

After this main introduction of understanding what is behind the warehouse systems, comes the flexibility topic. What is flexibility, in each way is important, the costs associated with it, and the necessary commitment to achieve it. The differences and similarities between efficiency and flexibility are another and an important part of the work, that most of the times, is the source of confusion. The following has also created special attention to the e-commerce theme, and the importance of this in the actual warehouses.

Still in the theoretical part, we point all the selected factors that can affect the warehouse flexibility. They are divided in six main groups: receiving, put-a-away, storing, pick-n-pack, shipment and others. Each of the factors has its own explanation of why it is important for the work. These factors are the base, and so, of extreme importance for the practical side of the work.

With the last theoretical part, comes the future of the warehouse. All the work refers to evaluation and data analyses to further improvements, and without presenting anything

regarding the “after-assessment” would be a mistake. In this section are presented some new systems that better illustrate how to achieve flexibility.

The second part of the work, the practical one, begins with a brief explanation about fuzzy logic. What it is and how it appears. Following this, comes the general advantages of fuzzy logic programming. In this section it is also possible to find why it is so appropriate to use fuzzy logic for this work, and not another programming language. The next step is how this language works together with our goal. The bridge is made here between theoretical selected factors that better described warehouse flexibility, and the fuzzy logic programming part.

Later on, some simplifications have to be taken in account, to make this work possible. All the simplification steps are justified and precisely described. The explanation of all the parameters in the fuzzy logic are explained. The work that has to be done, to achieve a warehouse’s flexibility final overall result is fully reported.

The final part of the work is related with results presented, and the discussions of these. Also a topic with recommendations and improvements for the work are included.

Ultimately, finishing the work with the conclusion, where an overall resume is made with some final descriptions.

# Chapter 2

# 2. Theoretical Part

## 2.1 Supply Chain Management

During the mid-1990s the term "Supply Chain Management" started to gain weight and the popularity started to increase. Supply Chain was no more than the name given to what already, in that time, existed, the map throughout the chain of production. From the raw materials till the final customer. [Wisner et al., 2008 p. 40] In 1982, when for the first time the designation was used by Keith Oliver in the Financial Times, nobody could think about the percussion that this ideology turned out to be.

Initially, was the attempt to improve the flow of information that could bring better results. The huge problem in that time was that the big industry was to far from the other parts of the chain, even further from the customers. The others chain's players in that time were just the retailers, selling by themselves the products directly to the customers. With the natural evolution, the retailers that were going to by the products to the big warehouse owned by the big industry companies, started to construct there own warehouses. This new retailer warehouses were much bigger than the other ones and with the advantage of storing products of different brands. In that time, the cost of area and buildings was almost negligible. [Richards 2011, p. 6]

Time passes, the evolution is natural. The customers now want cheaper and faster deliveries. The production changed from "push" to "pull", just in time (JIT) appeared, and the Kaizen, the general idea of improving constantly took place.

The reasons to hold stock by the companies changed substantially. In the past the reason was because the production was rigid to change, and there was not a quick response within the industry, in contrast with the fashion trends by the customers. [Rushton et al., 2014 p. 194]

Nowadays the reasons to hold stock are completely different. With big production migration to the east, the lead-time between production and delivery to the customers increased. Therefore, to cover that difference of times, big warehouses closer to the customers hold the product to hide that gap. The increase of the e-commerce justifies also the stock holding. It is a necessary quick answer to please everyone. [Richards, 2011 p.8]

All things considered, the supply chain is responsible to deliver the right products, in best condition, at the right time, in the right quantity at the best price.

One of the responsibilities regarding success or failure of the chain is the warehouses. They are in charge of picking and dispatching the right product and the right quantity.

They are also responsible to deliver the merchandise to the right costumer, at the right place and on time, through the accurate labeling. Best condition and the correct price are also constraints that can be regulated by the warehouse. [Richards, 2011 p.8]

What is happening within the warehouse is important not just for the success of the company, but important for all the actors of the supply chain, and the most important is the final client.

## 2.2 Intralogistic Systems

Trying to define an "intralogistic system" in few words is difficult. But if we have to choose a group of key words to describe the most important processes in it, they could be "merchandise flow" and "data processing". [STILL, web]

Intralogistic definition is not an old term, actually it is a recent term that defines exactly the keywords that were referred before.

Enunciating an intralogistic global definition written in the logistics journal: [Nenad et al., 2011 p. 3]

> *The new term "Intra-logistics" describes the organization, realization and optimization of internal material flow and logistic technologies as well as the goods transshipment in industry, trade and in public institutions by means of technical components, partial and full systems and services.*
>
> - *In the frame of "Supply Chain Management" intralogistic control the material flow along the complete value-added chain;*
> - *Intralogistic describes the internal material flow between the different "logistic hubs" - from the material flow in production, in goods distribution centers and in airports and seaports - as well as the related information flow.*

The name reflects "*intra*" from Latin which means "within, inside".

Trying to establish a connection between intralogistic term and the warehouse is simply all the flows and movements of merchandise and information within the warehouse walls. This information and goods have to be processed in the best way to achieve the company and client's goals.

## 2.3 Role of the Warehouse

### 2.3.1 Warehouse's Operation Types

As we saw earlier in this work the importance of the warehouse is undeniable. Now the importance is to relate the flexibility to each kind of warehouses.

In a demanding supply chain, with tough challenges it is very difficult to maintain, open, and have general types of service. The specialization is happening everywhere, not just in the warehouses. The companies have to specialize in small types of markets to achieve the success. All the firms that decided to specialize in a specific branch, realized earlier that was impossible to maintain an extensive service while trying to have the best answer to all the different challenges that the customers asked. To be more competitive is necessary to opt by a specific line of business, to narrow our goals' horizon. [Al Ries, 1992 p. 5]

The evolution happened exactly the same with warehouses. As different companies need different resources, distinct types of warehouses need different resources. The type of flexibility, or where the flexibility is more important within the company differs from each type of warehouse.

It is possible to define ten different types of warehouses: [Richards, 2011 p. 9-12]

***Raw Materials Storage***

*These warehouses store raw materials and components close to the point of manufacture.*

***Intermediate, Postponement, Customization or Sub-assembly Facilities***

*These warehouses are used to store products at different stages in production. These centers are also used to customize products before final delivery to the customer.*

*Postponement and sub-assembly activities can include the following:*

*-Specific packaging or labeling being changed or added, e.g. for store-ready items or printing in different languages;*

*-Computer assembly to include different graphics cards, memory chips, software, etc;*

*-Country-specific items being added such as electrical plugs;*

*-Special messages being added, e.g. stenciling of greetings messages on mobile phones.*

***Finished Goods Storage***

*There warehouses store products ready for sale, on behalf of manufacturers, wholesalers and retailers. They provide a buffer or safety stock for companies, enabling them to build up stock in preparation for new product launches, expected increases in demand and to deal with seasonality.*

***Consolidation Centers and Transit Warehouses***

*Consolidation centers receive products from different sources and consolidate*

*them for onward delivery to the customer or onto a production line. This can include just-in-time centers where automotive parts are delivered to a warehouse where they are brought together and sequenced for delivery.*

*They can also be retail warehouses where products from different suppliers are consolidated for onward delivery to the stores.*

*These differ from cross-dock centers in that production could remain in the center for a period of time waiting call-off from the final destination.*

***Transshipment or Break-bulbs Centers***

*Transshipment centers receive products in large quantities from suppliers and break them down into manageable quantities for onward delivery to various locations.*

***Cross-dock Centers***

*Cross-dock centers are seen as being the future for warehousing.*

*Efficient consumer response and quick response within retail require operations to be able to move goods quickly through the supply chain. Cross docking requires deliveries into these centers to be already labeled and ready for onward delivery. Here the items are identified and consolidated with other deliveries, ready for dispatch. Items should remain in the warehouse for as short a time as possible. Same-day dispatch is the target.*

*Although companies are beginning to realize the efficiency of cross cocking, a survey by Cranfield University (Baker and Perotti 2008) suggested that only 10 per cent of goods were cross docked, based on the response received.*

*Cross-dock warehouses or transshipment centers are also utilized in outlying geographic areas to transfer products onto local, radial distribution vehicles. This transshipment process can take place either inside or outside the warehouse. Typical cross-dock products are perishable items such as fruit and vegetables, meat and fish, which need to be moved quickly through the supply chain.*

***Sortation Centers***

*Sortation centers are used in the main by letter, parcel and pallet distribution companies. Goods are collected from all parts of the country, delivered into hubs or sortation centers, sorted by zip or post code, consolidated and delivered overnight to their respective distribution areas for onward delivery.*

*Today's retailers are also moving towards automated sortation centers with pallets being de-layered on entry, the use of mini-load systems for temporary storage and retrieval and finally automated pallet build on exit.*

***Fulfillment Centers***

*The growth of e-retailing has seen an increase in the number of customer fulfillment centers. These warehouses have been designed and equipped to manage large volumes of single-item orders. Grocery retail fulfillment centers have, in the main, taken the place of store picking for home-delivery orders.*

*These centers can also double up as returns processing centers as commerce has a larger percentage of returns than normal retail activities.*

***Reverse Logistics Centers***

*Third-party contractors are providing a service to retailers where customers return unwanted or defective items to the stores; the items are then consolidated and sent to the returns center, where they are checked and either repackaged, repaired, recycled, or disposed of.*

***Public Sector Warehousing***

*Outside the commercial world there are also warehouse operations that support the public sector, armed forces and the third sector. The increasing number of natural disasters such as earthquakes, droughts and tsunamis is resulting in third-sector organizations opening up warehouses in strategic locations across the globe. This ensures that they are closer to the disaster areas and thus able to react quicker.*

Through all the different kinds of warehouses explained before, there are some general processes that are similar in most of them. These processes are demonstrated in the next Figure 2.1. Some of the processes described in the next figure were not extensively described in the work; as returns, replenishment, and pre-advice for example. These small, but still important processes are not vital to describe the flexibility in a warehouse.

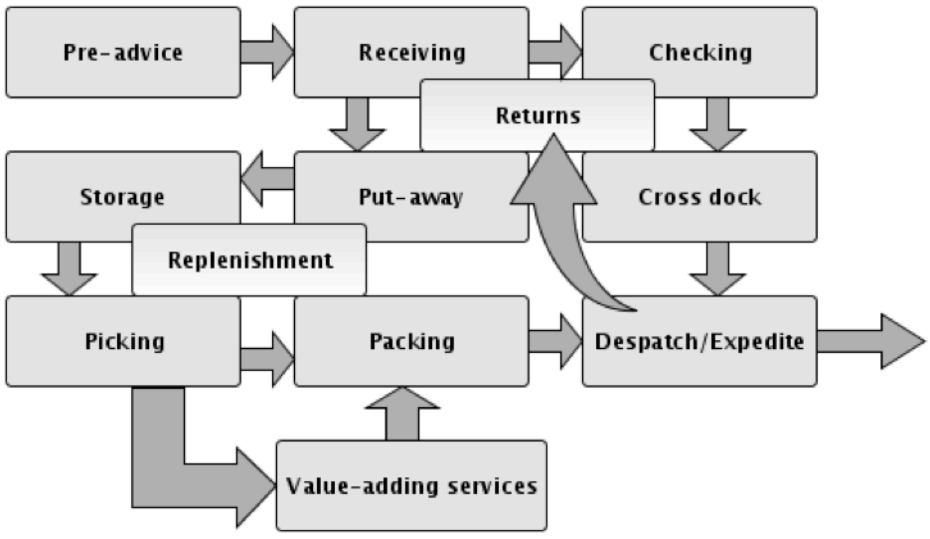


**Figure 2.1- Warehouse processes [Richards 2011, p. 45]**

### 2.3.2 Reasons to Hold Stock

The most important task within the warehouse is to hold stock. Wouldn't it be better if the merchandise was moving all the time?

As Richards (2011) refers, "*A supply chain with the minimum amount of stock within its pipeline is nirvana*."

The reasons to hold stock are very important in a warehouse, and it is necessary to understand that relevance to have advantages when holding stock. For that, the necessity of being flexible when managing stock is essential.

The society and markets unpredictability demand made the capacity of retain merchandise necessary. The same unpredictability that continues making the storage planning so difficult. With such great range of products, considering factors as size, weight, shape, volume size, number of different stock keeping units (SKU) and lines, all of these together become terrifying for a warehouse manager.

Through the next examples it will be possible to know the reasons to hold stock, and understand the importance of one of each factor. [Richards, 2011 p. 14-17]

**Uncertain and erratic demand partners**

> Typical events that are uncertain, such as the ones related with weather unpredictability or even sudden trends by someone famous that appears in the TV, etc. The brands have to be ready to answer to the final client, and so the warehouse appears with the stock in this process.

**Trade-off between transport and shipping costs, justifying large shipments**

> More you take, less you pay. This is a common sentence in the neighborhood grocery store, and also in the every day business. Large shipments normally have lower price per unit compared with smaller shipments. But it is also important to understand that if we have to accumulate merchandise to create large shipments, a place to store is needed. The trade-off between shipping cost and storing cost has to be well balanced. The buyer should have a strong belief and is capable to sell all the merchandise.

**Discounts via bulk buying**

> As a consequence of the last factor, sometimes, the forecast is not so accurate and the goods are not all sold. Another occurrence can take place. If the seller cannot sell at the original price, he can make a discount. But then the weights of all the costs are different. The correct way to act is that the whole-life cost should be calculated before order large quantities. The whole-life cost will be higher because it will contain additional storage and handling costs. Again, a

trade-off should take place between lower unit purchase costs and increased costs per unit.

**Distance between Manufacturer and the End Consumer**

With the production moving to Oriental regions the lead time grew substantially. The time needed between the order and the first arrival sometimes can be from eight weeks or more. Normally this value is between four weeks and eight weeks. To manage this gap of time between merchandise order and arrival, a large amount of goods have to be stored in a location closest to the client. Expensive local suppliers and producers, increased costs in transport and safety stock play the major rules in this type of store.

**Cover for Production Shutdowns**

The number of customers compared with the number of suppliers is incomparable. If the soul of all the business is selling, the goods must be always ready to deliver. Even in the case, if a factory is not producing for some specific and determined reasons. Vacations, machine maintenance, stock counts and strikes are events that should be taken into account when storing goods. Manufacturers should also build a safety-stock to ensure that they will always have goods to produce their merchandise. The supply chain cannot stop because of one or even more interruptions. The warehouses are there for that.

**Ability to Increase Production Runs**

Due to economies of scale sometimes a substantial increase of produced goods doesn't bring additional costs. The longer a production run, the cheaper the price is per unit to produce. Changes in the production run are unavoidable. Changing models, colors or customization has a price. The balance here is between the lower costs per unit versus the additional cost per unit for storage. The products that are produced in large runs must be stored.

**High Seasonality**

This reason to hold stock is related with some events or situations where there is foreseen that an increase of the demand will happen. Therefore, the warehouses accumulate more merchandise as a gesture of defense. Christmas, Easter, Valentine’s Day, Olympic games are reasons to hold stock.

**Spare Parts Storage**

The stops in the production lines bring a lot of additional costs. To ensure an uninterrupted production line operation, spare parts should be stock just in case an item becomes defective. The spare parts that ensure the safety of the production bring additional costs. The best balance should be between the cost

of the part together with its holding cost and the potential breakdown of the production line.

**Work-in-Progress Storage**

Some companies, normally associated with forecasting and high seasonality prefer to work in advance. This means, that they prefer to start to produce before receiving an order, then later, after receive the order. After, they proceed with the customization that each order ask for. But the main work that is similar to all the orders is previously done. The warehouse enters to hold to stock after the first production and before the customization stage.

**Investment Stocks**

Some specific type of goods can increase their value while stored. This is normally associated with products where the raise of the value is constantly happening. Fine wines and spirits drinks, cigars, precious metals, stones and fine art, for example belong to these type of goods.

**Document Storage**

Private and public companies have a law obligation to store documents over a certain period of time. These types of documents can be correspondence, invoices, accounts, etc. Sometimes these documents are kept just by choice of the companies.

**Third-Sector Change**

Third-sector organizations have to store vital equipment in preparation for natural disasters, items such as tents and survival equipment. These materials have to be stored and in the case of necessity, and they must be accessible in a very easy way.

## 2.4 Warehouse Manager Role

"*A good decision is based on knowledge and not on numbers.*" by Plato.

In the end, if the results are not positive there is always a responsibility in the warehouse case, the warehouse manager. Doesn't matter how automated or technology advanced is the warehouse, in the end there is just one responsible for the failure. [Richards, 2011 p. 26]

The market's competition has put the warehouse managers under pressure. In the old days it was possible to see a worker using a brown coat, grabbing a clipboard and a pencil in the ear, nowadays it's completely different. In the present days, the warehouse manager within the warehouse is seen as a super important job. [Richards, 2011 p. 26] The responsibility and the pressure are immeasurable. He/she is not responsible for just

the correct flow and store of goods. He/she is not responsible for just the customer's satisfaction. He/she is not responsible for just the security and productivity off all the workers. He/she is responsible for all of these aspects and even more. Incomprehensibly, the impression outside the walls of the warehouse is not understood.

The skills that a job like this require are a compound of abilities where it is possible to find in a variety fields of work. Ability to negotiate, information-technology skills, basic finance and business acumen, people management and an ability to motivate and lead large numbers of employees, these are the base skills to succeed. [Richards, 2011 p. 37]

The equilibrium that a warehouse manager has to establish can be split in three different fields: high customer service level, lower inventory, and low costs. These three factors are interconnected and inseparables. Other aspects can be referred to better explain the difficulty associated with this work. Is possible to enumerate four different points, as Richards write: [Richards, 2011, p. 28]

- *Increased throughput versus reduction in labor costs;*
- *Storage density versus quicker pallet extraction;*
- *Manual versus automated processes;*
- *Increased pick rates versus accuracy;*
- *Inventory holding costs versus cost of stock outs.*

To take a warehouse manager into consideration is necessary to understand the pressure that a warehouse manager has to handle. This pressure in a big warehouse can come from the most unexpected scenes. The challenges that he/she face everyday can be consulted in the following paragraphs. To summarize, all of these follow factors, picked from Richards (2001 p. 39) appeared as an answer to the rough competition present in the global market.

**Pressure to Reduce Operating Costs**

Due, one more time, to the reflex of the hard competition, companies are trying to get the lowest possible prices. Within the chain, warehousing and transport are the fields where the skepticism takes place, and where the pressure is bigger to reduce the prices.

Out sourcing and constant evaluations are the companies' attempts to assure the best prices.

**Achieving the Perfect Order**

The term "perfect order" is a recent key perform indicator (KPI) that represents the orders that has been delivered on time, in full, in perfect condition and

delivered with the correct paperwork. Paper work however due to technology advances it may disappear within the near future.

**Shorter Order Lead Times**

Order lead time, as it was previously explained, is the period of time between placing an order and the receipt of the order by the customer. As Filipe de Botton [Interview Web, 2013] refers, the differentiation of products seen by the customer is not anymore by the comparison of the prices and quality. The competition is so intense that the quality and prices between products are very similar between the range of products. The differentiation is obtained through the service quality, and differentiation in the product manufacturing.

Service quality is a competitive advantage through fast, timely, and accurate delivery. The best warehouses are those that can offer the shortest lead times, while maintaining costs and quality.

**Delivery through Multiple Channels**

The customers are becoming more exigent in the way that they would prefer to receive the goods. As a response for that, companies are always trying new methods and ways to surprise the final customer. That brings an additional pressure to the warehouse and to the warehouse manager. New ways of dealing/handling/treating different shipments than the usual is always a constraint. These different ways are completely related with the flexibility emergence.

**Smaller but More Frequent Orders**

The just-in-time method of production made the things more complexity to all the agents within the supply chain. In the same way, ordering through the Internet is the new way and has made an occurrence of grow. Accordingly, due to these reasons previously referred, the orders size became smaller, and more frequent. This has brought changes in the warehouse. Full-pallet picking is less frequent, to prevail carton and individual item picks. These are the best occurrences to evaluate if a warehouse is flexibility capable

**Greater Fluctuations in Demand**

Nowadays, stabilization and predictability are not the words that can define the global market. Perhaps, precisely the opposite. For some business's types, the situation is critical as for fashion merchandise, for example. Sometimes it is possible to predict some periods of the year, with peaks and downs, but in some business areas generally everything is fluctuating.

The warehouses have to be ready to store inventory or by the other hand be able to cross-dock merchandise during the peak periods.

**Increases in Stock-Keeping Units**

Differentiation and customization are the orders to try and sell more. Some companies prefer to package each product before the warehouse stage. This brings more stock-keeping units, with the hard task of picking one product of each category. This decreases the productivity rates drastically.

Other companies prefer the postponement option. This is the customization of the products within the warehouse. After the reception of the orders, with the extra components' information that the end customers want, it is possible to add the items in fault, making this one more step within the warehouse. This is more usual in technology products, such as computers. In this case some features can be chosen by the client when ordering the merchandise, such as more memory or even special offers with keyboard and mouse included in one special package.

**Labor Cost and Availability**

The image that a warehouse reflects to the exterior is not always the best. That is the main reason why general workers are not so attracted to this kind of work. To solve this problem, warehouse managers came up with some ideas.

Foreign workers are a good solution, but it is not so simple. The previous (original) workers should know how to speak a second language, such as the new workers. The warehouses should be prepared to be understood by everybody. From the faculty instructions until the package labels.

Other ideas from the warehouse managers could be the introduction of flexible hours of work. This can introduce student workers, that can handle school schedule with the warehouse times.

**Environmental Issues**

Another item that the warehouse managers have to deal with are those related with environmental questions.

In one hand the requirements are imposed just by the law of each country, in other hand, sometimes are the partners of the supply chain that demand more restricted rules.

The law that is imposed by the states of each country is related with the minimum effort that the companies can easily do. Sometimes this has a positive reflection on controlling some wastes that are afterwards reflected in fewer costs.

If the orders to be "green" come from the partners it is more complicated. Sometimes, the partners are competing in such a hard market that the minimum factor can bring the leader of the sales. If the chain's partners can sell while referring that they have a green product, not just by them, but also by all the chains that are behind the product is because they really put effort on that. In this case, they are not interested in following the law to obtain the minimum results. They want the best of each partner of the chain.

The warehouse manager is responsible to guarantee that everything is being done in this direction and more than that give the example to all the workers, by his/her actions.

This is related, for example, with the energy that can be saved in the heater system, refrigeration system or even through the lights. Warehouses also produce a lot of wastes as cartons and plastics. All of these items should be carefully handled.

**Data and Information Transfer**

Data is essential to achieve the best results in a warehouse. Collecting data, treating and examining it, is paramount to later improve.

Much more about this item can be described, there are thesis just about warehouse data.

Some of these previously items are described in full books or thesis. This is just a concise explanation, to understand the importance of a warehouse manager. If we think in just one of these topics individually, it could be relatively easy to manage it. But the real scenario is that in a competitive and top warehouse, the manager has to deal with all of these topics simultaneously.

It is important to refer and understand the pressure and difficulty that a warehouse manager suffers to try to establish a bridge between all the previous facts and our main theme, flexibility. It is easy to enumerate several of these topics intrinsically related with flexibility. Perfect order, shorter lead times, multiple channels of delivery, frequency of orders, fluctuations, etc. These are just some that are completely connected with flexibility. All the orders still have some weight and importance, but not as the ones referred before [Richards 2011, p. 38]

## 2.5 Flexibility Role

### 2.5.1 Definition of Flexibility

"*Change brings opportunity*" by Nido Qubein.

During the research for this paper, it was possible to find dozens of different meanings for flexibility. Some authors write that flexibility is the same as agility, or even responsiveness. Others can write establish differences between that two terms. It always depends how much deeper we want to go into the definition. The question is if that is the most important. [Bucki & Pesqueux, 2000 p.62]

The most important is to understand the base that is under all of the flexibility definitions.

Flexibility is often described as something that comes with a price, and at the same time, something too ambiguous to be managed efficiently. [Taylor, 1998 p. 30]

The term flexibility is generally described as the system capacity to react in case of changes, whether predicted or unpredicted. Again, some words are often used with the same meaning. Just when doing the exercise of trying to soundly define a term, it is possible to understand the small differences between words with similar definitions. For example, flexibility and agility. One more time, for some flexibility is different than agility, for others it is not.

Flexibility is the competence of being prepared for something that could happen unpredictably. [Brandenberg, web] It is the capability of being ready for different or unusual work circumstances. To be flexible, necessary antecedent planning in order to predict events that could happen in the future. In a very unconstrained way, it is something as always has a plan B, for every situation.

There are also some more extented definitions like Upton's idea, "the ability to change or react with few penalties in time, effort, cost, or performance" [Cousens et al., 2009 p. 359].

By the other hand, agility is the competence of being prepared for the surprise, for the complete unexpected It is the capability of reaction under unforeseen situations. [Brandenberg, web] For example, let's consider a practical situation to try to define agility. During heavy rains, resulting in big inundations, the search for pumps to take out the water from the buildings will overcome all the expectations. The way of acting of the companies and warehouses in this sort of situation is named agility. Perhaps, in a very informal way, agility can almost be called capability of improvising under stress and unexpected situations. [Duguay et al., 1997 p. 1188]

All things considered, there are different definitions for flexibility, with tiny differences between each other.

In any case, for this work, flexibility is the capability of reacting under unexpected events or occurrences, whether exists a precedent planning or no.

### 2.5.2 The Role of Flexibility in the Warehouse

When trying to realize a big picture about the evolution of the industry related with performance indicators, it is possible to distinguish three different waves: first, the concern about efficiency, then quality, and by last flexibility. [Suarez et al., 1995 p. 223]

From the times of industrial revolution until nowadays, the industrial scene has suffered considerable evolutions. In the beginning the target was the mechanization of almost all the stages within the industries. In that time the production was long and batch oriented. Goods were made in large quantities without any kind of customization.

With the evolution that came from Japan (Toyota Production System), efficiency was the main goal. Waste reduction was the aim. At the same time instead of batch orientation, custom products were adopted, following what clients really wanted. Japan production started producing focusing on merchandise. At the same time they were reducing the product line. The effects of all these actions were the increase of labor productivity and the decrease of the costs. The forecast, in that time already existed, but with far predictions. [Pegels, 1984 p. 3-5]

The next stage in the production was with the quality aim. Total Quality Management (TQM), made the quality paramount. Still with the idea of continuous improvement brought from the Japan model, and statistics process control. The forecast was still playing an important role, but this time with shorter and sharper predictions. [Khan, 2003 p. 375]

In the recent way of management, the search for speed and flexibility is the mark to reach. The companies became more vertical, and the fast flow of information is fundamental. The lot size of one is more appreciated by the clients than the batch order. The response, when using advanced systems of management, is immediate. In these systems, everything is computed, and there are no papers circulating around the companies. [Taylor, 2003 p. 20] In the next Figure 2.2 it is possible to check the

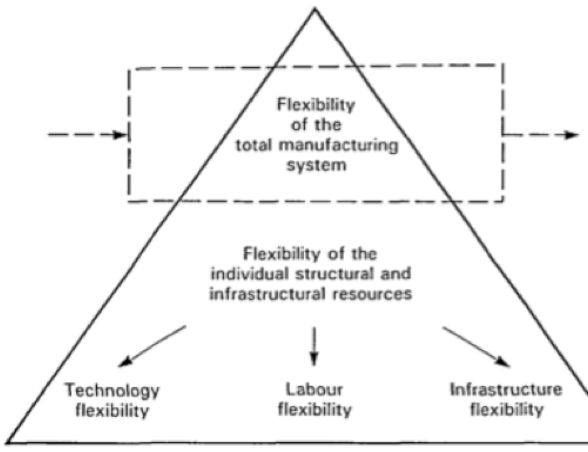


**Figure 2.2- Flexibility of the production system as a whole [Slack 2007, p. 37]**

flexibility sharing responsibilities through different manufacturing sectors.

Greis and Kasarda (1997 p.3) wrote about the response role of the supply chain, which can be perfectly adapted to the new trend of business presented nowadays:

> *Forecast-based production systems are no longer adequate to organize their operations around real-time information about shifting customer needs and about the availability of their productive capacity. They require not only up-to-date and immediate information about the location and disposition of all productive assets, but also information linking the location of the asset with available transportation opportunities. Under such conditions, logistics is becoming a primary enabler of real-time response to customer needs.*

In a society where the competition and the attention for the detail is growing, it is mandatory to achieve success to survive, the flexibility in the warehouse plays a major role in the supply chain.

Some years ago and even nowadays in the unsuccessful cases, the warehouses were/are seen as a waste of money, the role has completely changed.

The companies are not competing anymore among the others. We are facing competition between different supply chains. [Hoppe & Rice, 2001 p. 3] They have to cooperate among others, even try to establish partnerships, otherwise the success will be impossible to achieve (Figure 2.3). The companies have to help each other within the supply chain. If a mutual cooperation is not present than the supply chain will be unsuccessful. That means that the final customer, the client, will be unsatisfied with some aspects related with the product. The guilty is not of one company, it is from all the chain partners.

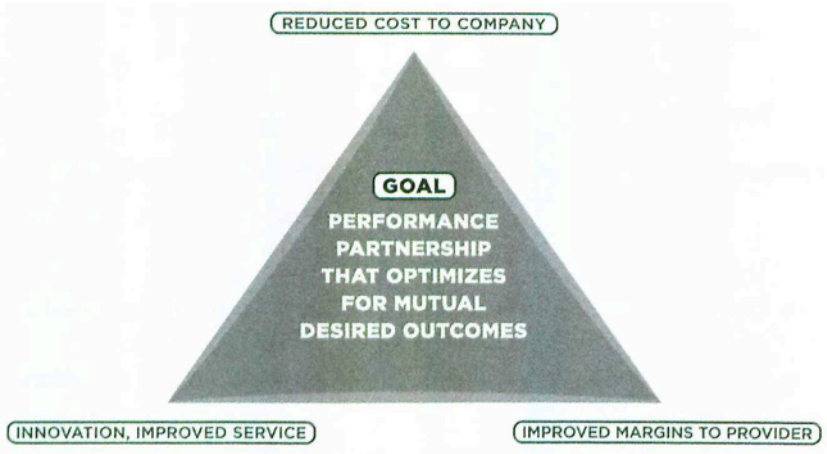


**Figure 2.3- Performance Pyramid [Vitasek 2010, p. 46]**

In these days, the customers' demand is much higher than years ago. More than that, we are living in a "pull" economy, where the "lean" is the rule to survive. That means that the most important actor in all the chain is the final consumer. He plays a major role

throughout all the work in the supply chain. The flexibility that is required to answer all the different clients necessities is extremely important. The trends are always changing, the latest fashion trend is always a different surprise. Between all the aspects that will be approached throughout the work, flexibility in the warehouse everyday is more of a crucial factor to captivate new partners and to maintain the ones that we possess. [Primrose & Verter, 1996 p. 4-5]

As Beamon refers (1999, p. 284) "*Indeed, flexibility is vital to the success of the supply chain, since the supply chain exists in an uncertain environment.*".

In the most common business days, unfortunately a common drawback happens every time. Delays are becoming ordinary from each supply chain partner. [Taylor 2003, p. 14] A supply chain where all the intermediaries play a perfect paper is almost impossible to obtain. This is one more reason why it is fundamental to be as flexible as possible. All the orders throughout the chain, since the process of the order (first stage), have dates to meet. If one process is late, the others will be late. This is because the ordinary supply chain works as a cycle, as it is illustrated in the next figure 2.4.

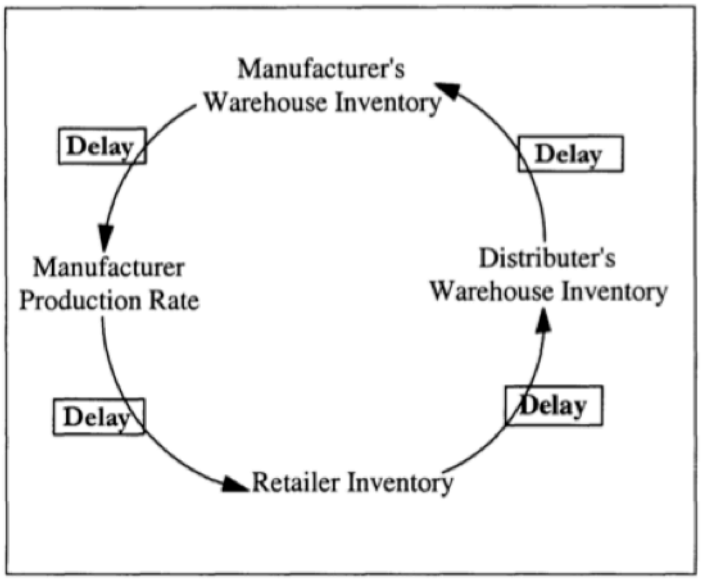


**Figure 2.4- Planning Loop [Taylor 2003, p. 14]**

This effect is also known as bullwhip effect. If one incorrect intervention takes place in one part of the chain, the effects of that intervention will grow in a bad way throughout the chain, as an amplifying effect. Here, enters the best and fundamental flexibility role. Flexibility can handle delays across the chain. Sometimes, can even make amends to the delays. [Paik et al., 2007 p. 310]

So, when we are dealing with delays, time is the factor against we are fighting.

> *Strategic flexibility, thus, depends jointly on the inherent flexibilities of the resources available to the firm and on the firm's flexibilities in applying those resources to alternative courses of action.* [Sanchez, 1995 p. 138]

### 2.5.3 Flexibility Costs

Flexibility is an optimal characteristic that a warehouse can and has to demonstrate, but it is not simple. Most of the times, flexibility is not the best way to reduce costs or get profit. Depends, above all, of the volume range variation.

Surprisingly, a flexible warehouse can bring higher costs per product, than a warehouse with less flexible capacity. It is necessary to be aware that between a small range of volume variation, it is better to have more rigid systems, than systems capable of leading with uncertainty volumes size. It really depends from case to case. [Baker & Halim, 2007 p. 130]

As we can see in the next figure 2.5, the variation of unit cost per volume of merchandise is lower (solid line) than the other line (dot line). The dot line represents a clearly rigid system that can handle in a more profitable way with small variations of merchandise. It is possible to conclude so that the solid curve represents a more flexible function, because its costs are more uniform across the range of volumes. What is

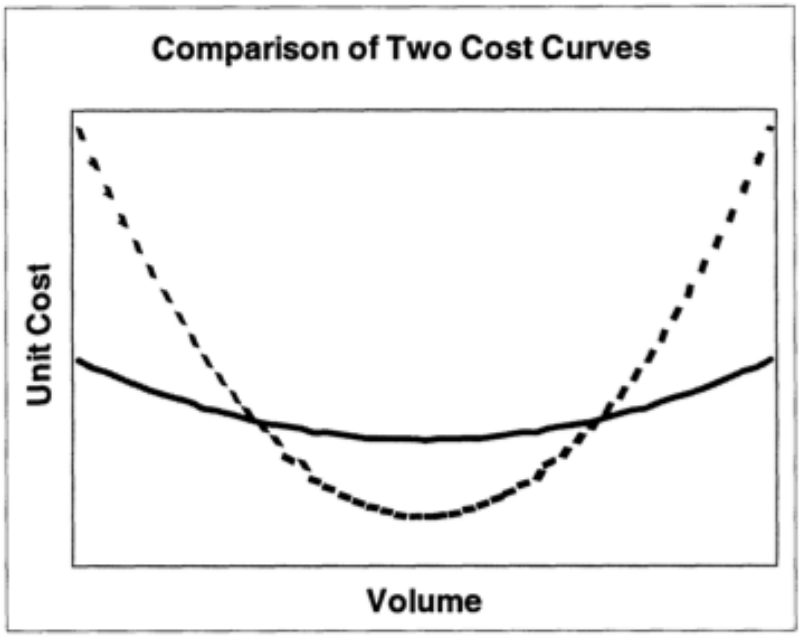


**Figure 2.5- Comparison of Two Cost Curves [Taylor 2003, p. 32]**

necessary to make reference is that with the less flexible system, represented by the dot line, it is possible to achieve a lower cost per unit that in the other curves. In the perfect conditions a rigid system, operating under the optimal circumstances will be cheaper (lower unit cost) than a flexible one, represented by the solid line. When ranging the volume, comes the best with the flexibility. When the associated costs in the rigid system rise sharply, in the flexible system, the variation is much lower.

### 2.5.4 Flexibility vs. Commitment

There are some companies, among the warehouses that in “self-defense” of the exigent and demand flexibility preferred to specialize in just one or few merchandise samples.

Like this it is possible to be better prepared for one specific type of market. Consequently maybe have the chance to raise profits, but being all the time restricted to one or few range of products. [Hymer, 1970 p. 441]

In the warehouses the same thing happens. In one hand, this commitment warehouses, see the profit margin raise, because they can have a low level of equipment and a short labor force, but by the other hand, they are prepared just for one or a small pallet of products. Because of that, the market where these warehouses are inserted is very restricted.

To be flexible is necessary to accept a commitment. A commitment understanding that the costs will raise, the efficiency will decrease. But by the other the hand, the positive side, our customers will appreciate and work more with us. [Spencer & Brander, 1992 p. 1602]

### 2.5.5 Flexibility in E-Commerce

The most recent and still growing market is the e-commerce. This type of market is characterized by the possibility of buying almost all the products available in the traditional market, but in a much faster and commodity way. Some years ago, and still now, the buyers were afraid of that experience maybe due to banking security reasons, nowadays it is more common to buy things through the Internet. [Durfee & Chen, 2002 p. 14]

The common e-commerce is B2C. During the year of 2013 the growing estimative for this type of business was of 17% comparing with the anterior year. [Richter, 2013 website] In fact, more data concerning e-commerce can be analyzed in the next Figure 2.6.

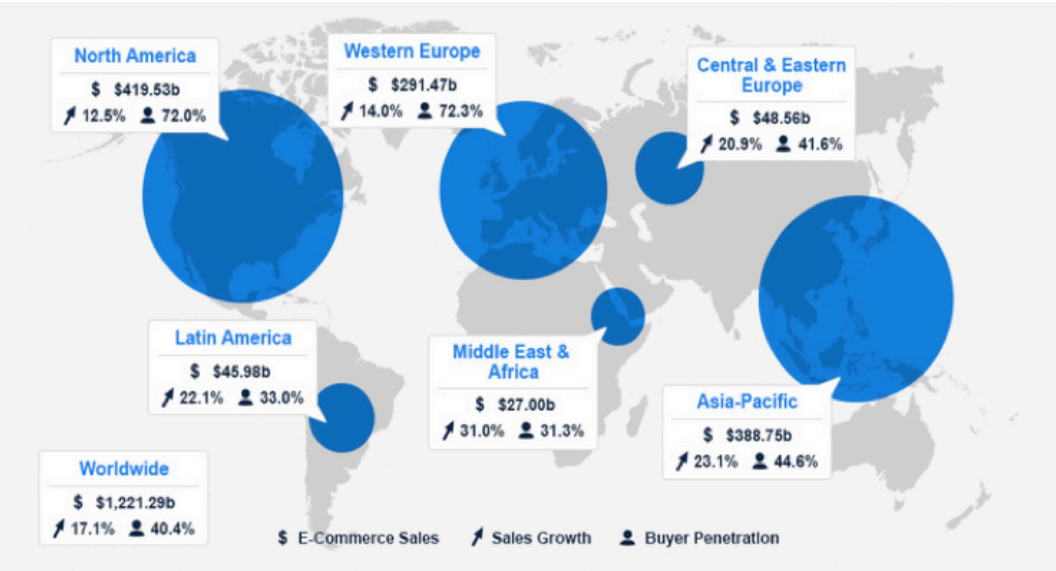


**Figure 2.6 - Estimated global e-commerce sales in 2013 [eMarketer]**

It is important to refer that not only B2C is being used by e-commerce, but also B2B. The companies realized that it is cheaper and faster to order and buy products through the Internet. [Durfee & Chen, 2002 p. 14]

This type of commerce brings big challenges for the warehouses. The e-fulfillment asks for the best of each section within the warehouse, principally the pick-n-pack and shipping stages. The cross-dock is also appreciated because it will help to increase the on-time shipping products rate. [Valle 2014, web]

One of the big adversities associated with this type of commerce is the seasonality. To refer, with e-commerce the market sensibility can possibly feel much higher, than in the typical store. People are more impulsive when buying through the Internet. The markets are more sensible to the real life of the consumer. For example, during the summer the orders for barbecues grow exponentially, and in the other hand, during Christmas the merchandise related with that season is more ordered. [Richards, 2011 p. 8] These are just few examples to exemplify the difficulties that the warehouse faces in these times of the year. To recall, most of this items are large and have bulky shapes, and so are more exigent to handle and to store. This kind of seasonality has big impacts in the function of the warehouses, and once again flexibility is paramount. [Richards, 2011p. 19]

Another adversity that is faced in this kind of market is the wide range of products that is dealt everyday. Worse than those are the low value and single item orders. These items are treated as normal products but they don't represent the same profit as the others. Is necessary to remind that the stages, as pick-n-pack for example, are exactly the same as the ones that take place to high cost items, but in this case, we are dealing with low-cost items. In the end, the costs of the warehouse are the same, but the margin of profit is much lower. [Richards, 2011 p. 19]

Nowadays, a customer is not anymore used to waiting long for an order. Even the tolerance for mistakes in the orders is lower. With that, comes the accuracy that it is necessary to achieve and maintain the customers. Accuracy and on-time delivery are paramount to preserve the clients. [Kallio et al., 2000 p. 75]

Inventory management represents another challenge. With the variation of ordered products, the number of product lines will put under pressure the pick locations while obsolete and slow-moving lines can utilize needed space in the warehouse. By the picking perspective, the increasing of product lines will result in search for solutions to the pick location. Mezzanine floors, flow racking and carousels could be examples of solutions. [Richards, 2011 p. 19]

The space is vital in a warehouse, and so, the stock turnover managing is crucial to get the best proper warehouse land use.

Another important fact about e-commerce is the large percentage of returns. In some cases, the number can reach the 40 per cent of outward volume. Most of the return items are still good to stock, that can be later resold, but first these items have to pass the quality check. [Richards, 2011 p. 19]

The next-day delivery is seen as the key to satisfy the client. Accuracy and speed are fundamental, and the warehouse manager is responsible to make the entire machine work in the best way. Adding to this, the possible client's interest of tracking the product, while checking the order condition. [Richards, 2011 p.19]

As Gwynne Richards (2011 p. 20) write, there are three types of fulfillment centers:

- *Integrated fulfillment, where internet sales are carried out alongside existing retail operations;*
- *Dedicated fulfillment, carried out in a purpose-built facility;*
- *Store fulfillment, which involves picking online orders from existing retail shelves for separate delivery ex store.*

The last option probably is not the best of an e-fulfillment operation. [Richards, 2011 p. 20]

In this type of market the flexibility is essential to survive. If a warehouse is not capable of dealing with this, for sure there will be another qualified one existing

### 2.5.6 Flexibility vs. Efficiency

The definition of flexibility and its role were described earlier in this work. The objective now is to understand the difference between flexibility and efficiency within the warehouse. These two terms are so often used in the literature, and each one crosses multiple times on the other field. [Adler et al., 1999 p. 43]

It's complex to define a narrow frontier between the pure definition of flexibility and efficiency.

Efficiency is paramount for a warehouse. Not committing mistakes through all the warehouse stages is vital. All the times that written accuracy is in this paper, it is always related with efficiency.

To reach a reliable and profitable warehouse is imperative to be efficient. To reach a warehouse that is capable to lead with the unexpected is imperative to be flexible.

Flexibility is the second step, after being efficient.

Nowadays, and in the most modern warehouses, the efficiency is repeatedly related with the software that is behind all the decisions and moves that we can notice. That kind of software is called warehouse management system (WMS).

By a simple definition written by Dave Piasecki [web] is possible to understand in what consists WMS:

> *Computer software designed specifically for managing the movement and storage of materials throughout the warehouse. WMS functionality is generally broken down into the following three operations: put-away, replenishment, and picking. The key of these systems is the logic to guide these operations to specific locations based on user defined criteria. WMSs are often set up to integrate with data-collection systems.*

When using these kind of systems, and if well implemented, the efficiency is almost sure.

The importance of this stage is to try to comprehend that flexibility is related with efficiency, but at the same time distant.

It is impossible to make an extensive definition of efficiency, otherwise, another thesis will be necessary. But it is necessary to understand that one big factor of efficiency is a well-organized body. An organized structure is present in all efficient warehouses. An ordered body is the fundamental factor to achieve flexibility. [Al-Darrab, 2000 p. 98]

Depending on what we are assessing, in a large number of factors it is possible to mark clearly if one belongs to the field of efficiency or if the other is closer to flexibility.

But there is no doubt that to have flexibility within the warehouse it is necessary to have an organized structure, brought by efficiency (Figure 2.7). [Al-Darrab, 2000 p. 98] But at the same time, in contrast, when we opt or when our clients ask for flexibility, suddenly, the efficiency is somehow putted apart.

It is notorious if we visit an efficient but less flexible warehouse, the organized body and the stress of traffic will be the main characteristics of the first comparing with the second. An agile warehouse somehow looks disorganized. But, once again, to have flexibility, order is everything.

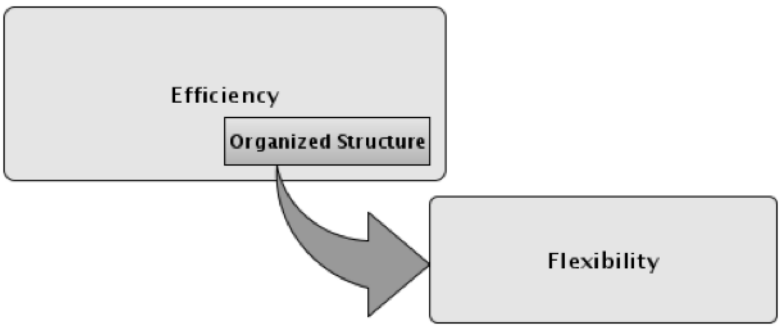


**Figure 2.7- Flexibility relation with Efficiency**

## 2.6 Resume of Factors

In the next section all the selected factors will be presented that will affect the warehouse flexibility. They will be organized by the main stages within the warehouse (receiving, put-away, storage, pick-n-pack and shipment), to get an easy reader, and a fastest consult.

### 2.6.1 Receiving

Receiving is one of the most important stages within the Warehouse. In contrast, there are some authors that defend that the most relevant steps are the ones that represent the work for the customers, such as pick-n-pack and shipping.

The receiving definition is nothing more than the process that allows warehouse operators to receive goods after a purchase order or an advanced shipping notice (ASN). [Berg & Zijm, 1999 p. 520]

Sometimes the first step that can happen in the warehouse will also be the last, such as cross-docking. If we pretend to cross-dock goods, they go directly to the shipment process. This process is appreciated by the clients, being a determinant origin of flexibility. [Boysen & Fliedner, 2010 p. 417] A scheme of how cross-docks work is represented in the follow figure 2.8.

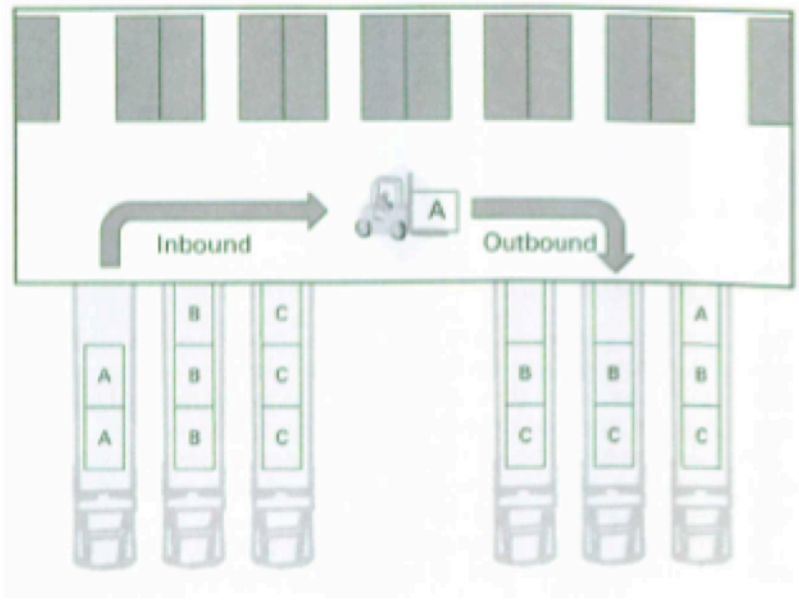


**Figure 2.8- Example of cross-docking [Richards 2011, p. 56]**

For instance, lets take in consideration that some steps of the paramount receiving process are skipped. The consequences that this can take are immeasurable. Furthermore, it will be very difficult to correct it or to handle the disorder caused for that incorrect inbound.

There are even some writers that advise to insert a step before the main receiving stage, the pre-advice stage. [Richards, 2011 p. 44] The warehouse manager has an important rule here. He/she should also take part in the negotiations, in the attempt to try to specify how the goods are received. Items per carton, cartons per pallet or specific labels required, or even the transport's modes are examples of what can be discussed.

Where is the flexibility that we are searching for? That is the hardest part. With so much "pre" preparation it is possible to have a very efficient warehouse, where all the system knows when and how are the goods received. It would be so much easier for the warehouse system, if all the goods received in the warehouse had a pre-advice before reaching the warehouse. [Richards 2011, p. 59] Please repair that this is not the essence of flexibility. Instead is the essence of efficiency.

In this perfect system, based on efficiency, the entire warehouse will work smoothly and without major problems.

Flexibility brings unexpected problems to solve with limited time to achieve the best solution, otherwise the warehouse system stops.

A large part of the warehouse customers prefer to not waste time and money associated with problems that are not from them. These problems are passed to the downstream partners in the supply chain. Instead of customers loosing time and money preparing all the orders like the warehouse partners would prefer, they would rather choose a partner that can handle different and distinct types of goods, packages and orders. Unsuitable packaging that overhangs pallets, incorrect labels, goods packed in quantities that do not relate to selling-pack quantities [Richards, 2011 p.45] are characteristics that take part in the flexibility associated with warehouse systems.

The next individual points represent the factors from the receiving stage that are directly related or could affect in a more considerable way the flexibility in the warehouse.

> **Volume Received** - this is an important factor in the warehouse flexibility. When it is not possible to predict what and how the goods are going to be received, this evaluates how is the ability of the workers and machines to deal with unexpected goods condition. This factor evaluates the quantity of goods received per an amount of time are reasonable. We should refer that this factor will always depend of two features. Merchandise characteristics and the warehouse goals. [Sangam, 2010 Web]
>
> **Heterogeneous vs. Homogeneous -** while some pallets are homogeneous with a fixed number of the same product, the majority of the pallets are heterogeneous. Heterogeneous pallets contain different kinds of product. Heterogeneous pallets required much more identification and putting away work. While some companies with big shipments don't have a problem with homogeneous pallets,

the smaller companies that ask for more flexibility prefer the heterogeneous model. [Westwick-Farrow Pty, 2007 Web]

**Receiving dock door utilization** - when related with the dealing ability of unexpected situations, such as the receiving schedule or the quantity of goods, how are the docks use is relevant. If the distribution of trucks is being well managed or if the automated machinery/labor work is being well distributed for example, are situations that must be under observation in this factor. [Bragg, 2011 p. 294]

**Compliance Labeling -** if everybody would have the ability to understand the fundamental information about the product that is being handled, this will represent an enormous advantage. In this way the adjustment that each good deserve within the warehouse will be easy and faster to understand and treat. This would be even simpler if the receiving goods came already with understandable and correct labels from the customers. [Richards 2011, p. 55]

Nowadays, there are a lot of different ways to label the goods. But the most common is the bar coding.

**Location Control** - this factor is very important, not just in the receiving process, but along all the warehouse system. It is extremely important to know exactly where are the products, every time. A warehouse that worries about flexibility has to know exactly where the products are. This process is easier if the warehouse system possess a warehouse management system (WMS). The best versions of this software can control all the movements and locations throughout the warehouse. [Bragg, 2011 p. 160]

**MHE** - Material handling equipment (MHE) is important regarding efficiency and flexibility. With this kind of equipment it is easy to get a faster process. There are a lot of different equipment types that can be used, always depending on the investment that the warehouse wants to do, but also depending on the type of the goods that are being cared for. The important characteristic in this factor is if the MHE used is adjusted with the goals of the customers and also with the goals of warehouse. [Richards, 2011 p. 237]

### 2.6.2 Put-away

Put-away is the process of moving material from the receiving dock and transporting it to a warehouse storage, replenishment, or pick area. The best putting-away practice is to put-away the product on the same day it's received. In addition, with this practice there will be no problems with space congestion, and transaction errors will decrease, while the products are not so susceptible to damage. [Vitasek, 2007 Web]

There are different types of put-away process: [Sangam, 2010 Web]

Direct Put-away - put-away directly to primary or serve locations

Directed Put-away - put-away directed by WMS

Batched and sequenced Put-away - received material sorted and put-away processed in batches

Interleaving - combine put-away and retrieval to avoid empty travels.

As it is possible to analyze there are very different types of putting away the merchandise. The best option is always to put-away directly from the reception stage to its final location and is often the favorite by the companies, as referred before as cross-docking. [Bragg, 2011 p. 47]

Efficiency is very close to flexibility in this warehouse main stage. When it is asked for flexibility in put-away process it is always related with the time response for different orders arriving and responsiveness. This step is characterized for its constant movements and transports. Here, the best way to have flexibility is through organization and discipline. This is nothing more than characterize efficiency. [Al-Darrab, 2000 p. 98]

**Put-away (man per hour)** - this factor is defined if the labor power is working well. If some goods arrive that are unforeseeable all the workers have to be ready. [Richards, 2011 p. 197]

**Utilization of Labor and Equipment** - flexibility is a feature that is only possible to achieve when all the equipment and workers are flexible themselves. The balance between the labor force and use of equipment is difficult to obtain. There is a little margin between what is the best way to work, regarding being efficient or flexible. So, the sensibility is essential to get a good result regarding flexibility. [Richards, 2011 p. 51]

**Perfect Put-away** - this parameter is itself a term of evaluation. We have to consider that when a warehouse system becomes more flexible, the rate of mistakes increases. Therefore, it is necessary to always beware of the precision of the process. [Vitasek, 2007 Web]

**Location Control** - location control is the kind of factor that will be present throughout the process of the warehouse. It is essential to know exactly, where are the products every time. [Bragg, 2011 p. 160]

**MHE** - as the parameter talked before, this is one more that will go with us throughout all the work. Efficiency and flexibility have the same targets with the use of this kind of technology. [Richards, 2011 p. 237]

### 2.6.3 Storage

"*The best handling solutions involve the least handling. Handling adds to the cost but not to the value of the product*." (Linde, 2007 p. 2)

When someone thinks about a warehouse, the main idea that comes is "a place to store". It is definitely correct. But it is much more than that.

This is one of the factors that has deserved more attention and consequently more development in the last years. Broadly there are two types of storage systems. One is the most common and usual, manual storage, and the other is automated storage and retrieval system (AS/RS). Currently exist a large number of manual storage types, and even more types of automatic storage. [Richards, 2011 p. 78]

> **Location and Cube Occupied** - together with flexibility, it is necessary to have efficiency, to know where to locate the merchandise and to know how much percentage of storage space is occupied. It is fundamental to have that information to take decisions regarding receiving more products, how/where to store, and even for the next warehouse stage picked and then shipped. [Richards, 2011 p.237]
>
> **Location/Inventory Accuracy** - this parameter is itself another term of evaluation. After knowing the information referred in the previous point it is necessary to know how much of that information is treated carefully, and so, what of that information is correct. This is elemental to ensure no problems in next stages. [Bragg, 2011 p. 296]
>
> **Inventory Days on Hand** - with the unpredictability of the markets, even with demand forecast, it is very difficult to satisfy all the needs that the customers ask for. So inventory in hand is the capability to respond quickly to this kind of situations. If on one hand, have stock is a positive signal, on the other hand it brings more costs. The balance between positive and negative inventory is not easy to obtain. [McBride, Web]
>
> **Storage Equipment** - there are almost infinite ways to store merchandise nowadays. Some systems are really expensive, but the correct choice always depends of the size and aim of the company. [Richards, 2011 p. 90]

### 2.6.4 Pick-n-pack

This process is the most costly process in the warehouse. Just like storage, pick-n-pack has been suffering a lot of modifications through the last 20 years. [Richards, 2011, p. 73] This stage is one of the most complex and challenging processes within the warehouse and has change a lot in the past years, because if the goal is to have an efficient and flexible process, to satisfy the customers, the work has to be guided by customer's orders.

In the past, pallets, cartons were the model to pick and pack. Nowadays, with demanding customers, the pick-n-pack section has to reinvent the old models.

Everything is involved on this stage: technology, labor, equipment and the layout of the warehouse. In the biggest and more complex warehouses the traffic/sharing of information between all the parts is vital for a general good function. Understand and act according to the data that should be collected all the time is another way to improve and to be more efficient and flexible. [Vitasek, 2007 Web]

The e-commerce introduction and the short lead times that the customers expect are being the leverage to innovation. The importance of this theme deserved a special attention in this thesis, in another previous topic, focused only in e-commerce.

Finally, this is the first stage of the warehouse where the final customer realizes if the warehouse is working well or no. This happens just now because all the stages before can be hidden to the customer, but not from this point ahead.

**Orders Picked** - this is the time to be fast and accurate. We are acting to the customers. This is the reason that we should evaluate workers and process velocity. [Richards 2011, p. 38]

**Picking labor vs. Equipment Utilization** - this factor is difficult to evaluate. The reason is that when thinking in flexibility it is not easy to get the best equilibrium between manual and automatic work. Automatic, if well implemented is more accurate, but with less flexibility. Depending on the aim of the warehouse, the percentage of each type of work should be well balanced. [Richards 2011, p. 86]

**Picking Accuracy** - this is the principal factor in this stage. To not have any kind of mistake when picking is the best way to operate. Not even the best warehouse can have 100% of accuracy. The average is around 97.7 per cent. [Richards, 2011 p. 60]

**Order Pick Cycle Time** - this is the second factor in this process. The time of goods traveling through the warehouse could decrease if it will be possible to have access to data and statistics to posterior analysis and improvements. For example, a palette of products that is ordered multiple times should be close to the shipping area and not in the last section of the storage area. This will decrease the picking time. [Bragg, 2011 p. 285]

**Picking Documentation** - the documentation should be clear and obvious at the same time. It would be perfect if a non-worker could understand all that is inserted in the picking data. That will mean that all the warehouse data is clear of confusion and ambiguity. With this simplification the flexibility is improved. The information will flow naturally.

**MHE** - as discussed earlier, and referred that will join us through all our way, the material handling equipment plays an important rule. Efficiency and flexibility are again working together. One more time, it is necessary to remember that the use of equipment and technology is not always the best option. It depends all the times about the goals of company and customer. [Richards, 2011 p. 237]

### 2.6.5 Shipping

Shipping is the last process in the warehouse or could be just the second and last in case of cross-dock. It is the last step to deliver the product to the customer and must not be neglect. Normally, if all the previous steps are well performed this one should flow without any major problem. [Vitasek, 2007 Web]

**Order Process for shipping** - this factor defines the responsiveness to unexpected affluence of orders. Good team work must always be ready for the unexpected, this is imperative. A warehouse is never working at the same pace. That is why flexibility is so urgent. [Vitasek, 2007 Web]

**Shipping docks utilization** - the layout and the organization of the warehouse play major rules regarding the efficient warehouse operation. The percentage of docks being used should represent the efficient layout and dimension of the plant project. Sometimes, the problem is the organization and the distribution of merchandise through all the docks. [Vitasek, 2007 Web]

**Perfect Shipping (in condition & on time)** - here it is presented itself the evaluation by the direct clients. Nowadays it is not enough of a factor of satisfaction to present the merchandise to the customer without any kind of damage or on time. There are more features that make the difference between companies. But these two facts are still primordial in the satisfaction of the customer. These two factors are imperative to compete in this global market. [Vitasek, 2007 Web]

There is a point to take in consideration, that sometimes the delivery is late to the customer and the fault is from the transporter company, and not from the warehouse.

**On-time ready to ship (timely order pick within the warehouse)** - this is the parameter that defines the necessary time within the warehouse to pick and present the product ready to ship. This is important to evaluate the time wasted within the walls of the warehouse, and not to evaluate some other supply chain processes. [Richards, 2011 p. 238]

**MHE** - the last step in the warehouse should have the support of all the technology possible, however sometimes, trying to improve the flexibility it is

difficult to achieve the balance between labor work or machines. [Richards, 2011 p. 237]

### 2.6.6 Others

There are some factors that are difficult to integrate into the five typical processes of the warehouse. That is why this section exists with general factors.

**Forecast / Seasonality** - forecast is an estimation of future demand. Most forecast use statistics from the earlier years to calculate future demand. Variations of seasonality and trend are often necessary. This is always an attempt to have a reasonable approximation, but it is fundamental in the flexibility of the company. [Forslund & Jonsson, 2007 p. 94]

**Inventory Levels (Fill rate)** - this parameter relates order-processing measurement that quantifies the ability to fill orders. There are different ways of measuring fill rate. For example, comparing the number of line items shipped complete to the total number of lines ordered. This parameter is really important when related with flexibility. Unexpected orders can be easily filled out. [Richards, 2011 p. 238]

**Stock / Inventory Accuracy** - the importance of knowing exactly what is within the warehouse is very important. The developments of recent technology systems make this parameter a little obsolete. But in the old warehouses, where the information is not so accurate the lost of stock in the storage area was a problem. Everything should be registered and with clear information. With that all the stages after storing will become easier. [Bragg, 2011 p. 296]

**Warehouse Management Software** - all the warehouse electronic management system is based on this kind of software. The use of this kind of program is an important step to increase the efficiency in the warehouse. If well implemented and adapted to answer to all the necessities of the company it is a very helpful toll. There is only one lack of performance in this kind of programs. They are so perfect with distribution and organization that sometimes the flexibility is compromised. A good balance between common labor works complemented with machine labor is the best solution for the flexibility. The latest evolutions of this kind of system will appear in another section in this work. [Richards, 2011 p. 147]

**Use of radio frequency identification (RFID) vs. Barcodes** depends in which situation or of the company aim. Barcodes are cheaper to implement but RFID can handle much more data. Having this kind of identification (RFID) is always a positive point. This will lower the use of the paper, which has a large number

of defects. More information about both kinds of technology will be discussed later in this work. [White et al., 2007 p. 121]

**Warehouse Layout** - this parameter plays an important role in our main target, flexibility. The layout in a warehouse has a large influence regarding flexibility parameter. The knowledge depth of such factor makes it impossible to study and discuss it here. [Hassan, 2002 p. 435]

In the Figure 2.9 it is possible to analyze how are the connections of all the main stages described before.

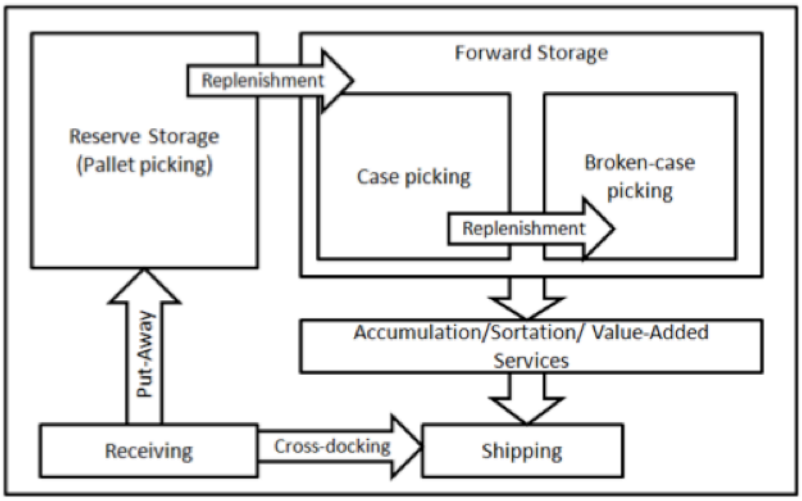


**Figure 2.9- Functional areas in a typical warehouse [Ayodhiramaujan 2009, p. 4]**

Making the bridge between the theoretical part of this work and the practical is a sensible process. Each of the parameters previously discussed should have limits separating the good from the bad, or the much/many from the little/bit, and so much more, depending of what is going to be evaluated. One thing has to be taken in consideration, if we are developing a framework to assess the flexibility within the warehouse, even the programs have to be flexible. Sometimes a warehouse will appear with a complete different approach with one that we are taking in this paper, and that doesn't mean that one of the two is going in the wrong direction. It means, that sometimes in the management world some decisions have to be taken to try to insure the total satisfaction of the client. So, when evaluating a warehouse, with the factors that we considered the most important regarding flexibility will not exist any term of comparison between our terms of evaluation and what is being practice, a deep reflection should take place. It is very important to think of the new approach that what the company is following actually works, and then finally tries to adjust to the evaluation scale imposed by this paper.

The evaluator should be flexible to different kinds of process that he/she will find during the warehouses assessment visits.

## 2.7 Warehouse's Future

In the next topic we observe what we can expect in recent future. In which direction it will go, what should be better to improve the flexibility. It will not be extensive regarding specific technology or machines.

This topic could be placed in the end of the work, or in here, in the end of the theoretical part. In any case, it is a topic that can be consulted when its needed, or principally after the final assessment to get further information and elucidations.

The act of writing about evolution and innovation appears not to be the correct method. Writing is a slow process, and the time wasted to think what to write is not a synonym of efficiency. While I am working on this work, everything is happening outside. The world is on a constant run to see who first reaches the goal. In a competitive market as it has been described through all the paper, having the best product or the best service is not enough to win. At least, it is necessary to equal the quality of what we sell. But that is not enough. The differentiation is the key. [Filipe de Button interview, 2013] Differentiation is nothing more than have different processes, different ways of doing the same or even better than the others. To achieve this distinction it is necessary to look for new processes but also pay attention to the new technology that comes out everyday. The technology rhythm is dizzying and frightening. [Filipe de Button interview, 2013]

The evolution and innovation allied with technology are the secrets to win.

Partnership model of evolution would be the best option to get the best practical results. Most of the time the technology developers are to far from the reality, and when developing new technology they are not solving real problems. In our specific case, the warehouse managers should have the responsibility to work together with developer companies to solve real problems and to try to get better results for both parties. The partnership relation model should be best way to solve problems and to improve. [Maheshwari, 2006 p. 278]

There are more ways to get better results. The future is exactly that. Finding solutions for the problems that we face everyday, or by the other side, discover niches where it is possible to introduce something completely new that will help in the actual tasks.

But lets stop for a moment with technology. Trying to achieve the best process among the labor workers can be also considered innovation and evolution, called processing evolution. This last type of innovation is one the best ways of improving, regarding investment money saving. Of course, that the curve that is possible to reach in process evolution has limits. Sometimes, the markets and necessities change so fast that it is impossible to achieve the best result within the company. Flexibility here is mandatory. The market's stability will never pacify. [Baker, 1999 p. 52]

### 2.7.1 Reasons for Improvements

For now it is possible to enumerate different reasons why we need to improve in two different aspects, process and hardware: [Richards, 2011, p. 297]

- The global population is getting old, statistics show that. While the population is getting older, the necessity of more automated processes become paramount;
- The valorization allied with inflation will make the space more and more valuable (excepting some special cases), and so the necessity of storing in a more efficient way, saving space is essential;
- Sustainability, the green problem. As discussed before in this paper, being environment friendly sometimes is a big step to conquer or retain customers;
- Essential resources that big part of the warehouses uses nowadays are fossil fuels. With the proximity of the provision's end the prices will continue to raise, and so the emergency of different kind of energy is fundamental;
- Pressure of companies to share work will continue to grow, and the warehouses must be prepared for that. Sometimes sharing services equals sharing costs. Sometimes it is a good option, sometimes not. The partners supply necessity of knowledge that the chain partner will work and cooperate for both of them, like a team. The change from being a client to became a partner.
- The flexibility that the clients/partners ask everyday to answer to the exigent final clients of the chain. The target is and it will always be the final customer, and so, all the chain has to work with that in mind. The changes will have to happen everyday. The most adaptable wins.

Even the name "warehouse" feels now clinging to the past. The new trendy way to call them is "Multichannel distribution centers". [Paskewitz, 2001, web]

### 2.7.2 Future's Landscape

One author reported back in 2010, the scenery for 2016 warehouse's characteristics. They were focused on four different aspects. [Capgemini, 2010 p. 7]

The information will be shared by everyone in the supply chain. "Based on a multi-partner information sharing among key stakeholders: consumers (the originators of the demand signal, either from home or from a store), suppliers, manufacturers, logistics service providers and retailers.". [Richards, 2011, p. 298]

The transportation should be different. "Once produced, products will be shipped to collaborative warehouses in which multiple manufacturers store their products. Collaborative transport from the collaborative warehouse will deliver to city hubs and to

regional consolidation centers.". [Richards, 2011, p.298] The systems and the sharing of responsibilities should be different.

The function and goal of the warehouses will depend of the warehouse's location. "Warehouse locations on the edge of cities will be reshaped to function as hubs where cross-docking will take place for final distribution. Non-urban areas will have regional consolidation centres in which products will be cross docked for final distribution.". [Richards, 2011, p. 298]

The last is about final distribution. "Final distribution to stores, pick-up points ands homes in urban and non-urban areas will take place via consolidated deliveries using efficient assets.". [Richards, 2011, p. 298]

The definitions of a warehouse will change in the next years. The name warehouse will change for more precise definitions, such as consolidation centers, regional hubs or shared-use facilities. Simplifying, what will happen within the walls of these previous centers will be approximately the same as nowadays, but divided in more stages and with that bringing more efficiency and flexibility. Warehouses with a general meaning will continue to have a crucial paper in all the game.

For Capgemini the shared-user operations will continue to grow and to be even more intense. Retailers and manufacturers will collaborate even closer, by "extending the consolidation centre premise to cover multiple retailers", ensuring even greater warehouse operation and "full truckload deliveries in all directions.". [Capgemini, 2010; Richards, 2011 p. 298]

These previous methods to succeed have to share between all the members, high levels of trust and commitment, among all the contributors. The main and general idea is to completely eliminate all the waste that still exists in the distributions processes.

The idea of waste is generally and the majority part of the cases associated with problems of space to store goods. Lack of space is the most frequent complaint among warehouse managers. In Richards, are referred three different examples of space wasted. These situations were found during an audit, where the space was the principal complain. "Half-height and quarter-height pallets taking up space in two-meter-high locations", "part pallets of the same product spread over a number of different locations", and "over 10 per cent of the stock was obsolete.". [Richards, 2011, p. 301] These are the kind of mistakes that are always happening in a warehouse.

There are other common types of wastes in the warehouses. Normally related with time in the receiving and dispatch bays. If the orders to receive or dispatch are usual and with some similarity between the previous, or if there are some kind of agreement with the partners about how the goods should be packed and labeled, there is no problem. But

after all this work, flexibility is mandatory. If we are not ready to be flexible, wasted time will occur.

The more radicals thinkers believe that the storing process, the stock can be surpassed. In an era where the e-commerce plays a important rule, and the fulfillment centers are more developed, when the cross-docking is becoming more usual, the stock could disappear. [Richards, 2011 p. 302] But it will always exist, because the goods manufacturers and the consumers are the ones that own the supply chain. If by one side, the manufacturer wants to produce in the cheapest way, and that sometimes means produce in big quantities that he can not store, and so enters the warehouses, the other side is more exigent the final consumer. They want the correct product, without damage, as fast as possible. These are the reasons that make that in a recent future make impossible the full elimination of stock. [Biggart & Gargeya, 2002 p. 200]

### 2.7.3 Different Scenarios

Regarding the warehouse itself, the future of it can flow in two different directions. One that is more obvious thinking in the last years of this century, fully automated, where technology plays the major rule. The second suggests that humans will continue to have an important paper in the warehousing systems. The investments and advantages of them are different.

In the first one, the most recent technology is working. The humans will almost disappear. The ones that will stay in this scenario will be IT and equipment service engineers, to guarantee that the process will never stop. These warehouses must work 24 hours per day, and will be “green”. They will have the roof equipped with solar panels, not just to run the warehouse, but also to provide energy to all the vehicles that should operate with electricity, and not fossil resources. [Richards 2011, p. 303] These last warehouses will be really good when facing run costs, and still in general efficiency. Because the purpose of this work is about flexibility, is not the best type of warehouse regarding this parameter. The fully automated warehouses will have problems with single orders, with different packages sizes and formats. For everything to work properly almost all of this parameters have to be standardized.

By the other side, the second type of warehouse, where the humans will have a big rule working together with the machines, faces another type of advantages and disadvantages. The biggest disadvantage will be without any doubt the investment necessary in labor workers and machines. But here the advantages play a big importance, as it after described: [Richards 2011, p. 306]

- *High levels of accuracy;*
- *Driving to wrong location is eliminated;*
- *Reduction in order-picking mistakes;*

- *Greater operation comfort;*
- *Less stress for the driver;*
- *Up to 25 per cent higher pick rate;*
- *Higher order-picking quality;*
- *Distance and time optimization;*
- *Saves energy;*
- *Distance optimization means energy optimization;*
- *Reduction in lightning within aisles is possible ('pick by light on truck').*

In the previous advantages for the second type of warehouse, it is evident the efficiency improvement. One more time if the flexibility is improved, it is just due to the general efficiency improvements that drag in someway flexibility with it. No doubt, that the type of operation that involves the direct supervising of a human, and being the person, capable of interact with the process, will bring improvements in the flexibility's field.

As it was said earlier in this work, the difficulty nowadays and the same for the future, will be to find a good commitment between efficiency and flexibility. It will depend on the company's goal. A warehouse with more labor work will always be more flexible than a warehouse fully automated. The opposite is true, when trying to be more efficient.

### 2.7.4 The Happening Future

There is another kind of technology that will combine even in a more futuristic and better way the balance between automatic and labor work. It is called Knapp's optically guided picking system. This system blends the best of technology and the best of labor workers. "The picker wears a pair of glasses and is guided by the system to each required pick location using superimposed arrow symbols directly in the field of vision of the operator via a head-mounted display. At the pick location the goods to be picked are identified for the picker and integrated camera reads barcodes, lot numbers and serial numbers to confirm the pick without any further human intervention. A digital display, will show the number of items to be picked." [Richards 2011, p.306]

It is thought that this system will provide even better results than the actual advance system based in voice orders. The only equipment that the workers have to wear, as its shown in the next Figure 2.10, it is a simple pair of glasses with normal size and weight. In the same way as the voice-direct picking system, it allows the worker to have free hands for picking, and the training is quick.

**Figure 2.10- Knapp's optically guided picking system [http://warehousenews.co.uk/]**

# Chapter 3

# 3. Practical Part

## 3.1 Fuzzy Logic Definition

"*The closer one looks at a real world problem, the fuzzier becomes its solution.*" (Lofti Zadeh 1973).

The real world is too confused and with a disorder degree that makes it impossible to describe an event with just a "yes" or a "no", a "true" or a "false". There is always a "if", a "when", even a probability of something happening that it is not expected. "Many", "tall", "much small than", "old", are just some examples that a computer with a binary system can not properly describe. An occurrence is most of the times related as a comparison of terms and situations. Accordingly, the fuzzy logic tool appears where we can define a fuzzy system or vague concepts. Consequently, with this tool it is possible to define in a friendly process what we can capture from each situation, difficulty independently. In addition, we can describe what we really see, or what is really happening. In other words, it is the method of programming what can't be easily programmed.

Lofti Zadeh introduced the fuzzy logic approach in 1965, since then it has been applied to many fields, from control theory to artificial intelligence.

Specifically, fuzzy logic contributes in a very important way, mostly because we can define an event between the common values of 0 to 1. It is impossible to do it in binary language. Therefore, we have the possibility to define the uncertainty that is related with almost all the occurrences that happen beside us. In short, fuzzy logic provides the capability to compute human reasoning capabilities. Nevertheless, as once Zadeh remarked: "*In almost every case you can build the same product without fuzzy logic, but fuzzy is faster and cheaper.*"

## 3.2 Fuzzy Logic Fits the Assessment

The complexity associated with all the stages within a modern warehouse is just unbelievable. The size of each warehouse, also the system complexity, in addition with a prompt answer that the customer demands, can most of the times cause a lot of problems. The evaluation of the individual systems in the warehouse is very important. With an evaluation and data that defines the system, the manager has the improving responsibility of all the aspects where is possible to do better. Evaluation is the best method to discover the problems source.

The model presented in this work does not pretend to modify or improve the way in which small or individual evaluations are made. This work pretends to collect the most important information from and techniques used in each type of evaluation and link them all in one global flexibility evaluation for the whole warehouse system.

It is difficult to know what should be measured and to know the exact weight of each performance indicator. They depend mostly on what the customer pretends and also on the company aim. It is known that the investment effort in physical systems and in people grows along with service quality.

In a warehouse the decisions have to be made quickly and on time. Everything is changing quickly. Therefore, the way the systems and operations are evaluated is very important. In a system where everything is changing, and all the orders or requests differ from customer to product, the method of estimating the quality of the system is complicated but also needs to be flexible. It is not possible to define a system just with numbers, because our way of evaluation is based on constant comparisons with other kinds of systems or solutions. Even if two systems appear to be similar, sometimes big mistakes are made because of such assumptions.

It is possible to enumerate some observations to demonstrate why and when it is appropriate to use the fuzzy logic method: [The MathWorks 2014, 1-6]

- Fuzzy logic is conceptually easy to understand;
- Fuzzy logic is flexible;
- Fuzzy logic is tolerant to imprecise data;
- Fuzzy logic can model nonlinear functions of arbitrary complexity;
- Fuzzy logic can be built on top of the experience of experts;
- Fuzzy logic can be blended with conventional control techniques;
- Fuzzy logic is based on natural language.

This is where the fuzzy logic applies.

One of the major advantages of writing this program using fuzzy logic is the level of flexibility that we get from it when trying to evaluate a flexibility warehouse system. As we said, the fuzzy logic program has to have its own flexibility. In other words, there are a large number of different warehouse types (sizes, target, industry, etc) but with that comes the best advantage. With fuzzy logic we just need to define one type of program, nothing more. Because, one more, it will be flexible on its own. Consider two different types of warehouse, warehouse A, that represents a cross-dock centre, where a quick process is all to satisfy the customers, and where the items should stay in the warehouse for as little time as possible. In contrast, there is warehouse B, which

represents public sector warehousing. The purpose of the latter is nothing to do with the purpose of warehouse A. This serves the population when something is needed and in extreme cases, the products are available to everyone.

Now let's take one factor into consideration when comparing these two warehouses. For example, the quantity of orders accepted in the entrance in one day. The quantity of orders accepted in the warehouse A cannot be counted, compared to warehouse B. In the opposite way, there is a factor that we can compare in both of them. Which one of them receives the orders more efficiently? Receiving more is not always better, sometimes is the complete opposite.

Most important, and what is essential to understand, is that units or the real numbers don't have any weight in a fuzzy logic problem; everything is relative.

We can add to this explanation another worldwide and famous example.

The height of a population. The oriental average stature is known to be short. But what is considered low? The term low itself is not a good measure. They are considered short, for example, when compared with southern European average stature. But the latter are considered short when comparing with the average Dutch population height. Here is one more example showing that everything is relative. It always depends on the terms that you use to compare.

## 3.3 Work Simplification

Analyzing the large number of factors that were explained before one-by-one, it is easy to confirm that the warehouse flexibility assessment is not an easy operation. This complexity can be dissolved in two different ways.

First, the hard task of finding out what each of the factors means. This includes the correct interpretation of the factor and then the attempt to establish the relation from the theoretical factor to the practical warehouse facts that are being evaluated. The second task is attempting to find an assessment relation between the grades given in the theoretical framework and the practical warehouse. This last step should be an easy decision to make, since this thesis is all about relating the warehouse practical side to an unchallenging theoretical assessment, by the correct and simple correlation of actions and factors that happen everyday in all warehouses.

The list of all the factors, is divided by six different main groups regarding the main stages in warehousing systems:

- Receiving;
- Put-Away;
- Storage;

- Pick-n-pack;
- Shipping;
- Others.

Each of the main groups is sub-divided by the factors that will ultimately be used in the assessment. The list of all factors is long, and in that resides a significant problem. An important change of direction in this work is taken, due to the large number of factors collected.

As was written in the beginning, the main target of this paper was the overall flexibility warehouse evaluation. In the ultimate evaluation it was supposed to be possible to know all the factors that could compromise or benefit the flexibility in a warehouse.

Fuzzy Logic tool by Matlab seemed to be the best option to do such a task, where it was possible to conjugate a fuzzy logic approach and compute it in order to get an overall flexibility result, or grade.

Two different limitations appear when developing the assessment tool: software limitation and time. With fuzzy logic toolbox being an intuitive instrument to work and simulate different situations under different work ambiences, some limitations appeared in this work. Having collected 35 distinct factors, and fuzzy logic being able to handle and to compute all of them was not the problem. The insertion of all the data and the adjustment of all the settings was the real problem. This task turn out to be really time consuming.

Just after understanding how the fuzzy logic toolbox works, explained in the section 3.4 of this work, it is possible to comprehend that is necessary to write one fuzzy rule to each possible option. For example, to assess only the Storage group, we have to take into account the 4 different factors within this main general stage. They are:

- Location and cube occupied;
- Location without inventory discrepancies;
- Inventory days on hand;
- Storage Equipment;

Now let's consider that for each one of these sub-factors, we can assess them with five membership functions (MF). These MF are represented by curves, each of which is associated with a real description, as for example, for the factor "Location without inventory discrepancies" five different levels can be correlated: *Low*, *About Low*, *Average*, *About High* and *High*. These different grades are named as linguistic values.

Now the real problem: to establish just one fuzzy rule, it is necessary to associate each one of the sub-factors with a different MF (linguistic value) and to group all of them

under one large IF-THEN type of rule. The best way to understand the problem is to present an example of how the fuzzy rules work:

IF **Location and cube occupied** is *High*, IF **Location without inventory discrepancies** is *High*, IF **Inventory days on hand** is *Average*, IF **Storage Equipment** is *High*, THEN **Storage Flexibility** is *High*.

IF **Location and cube occupied** is *Low*, IF **Location without inventory discrepancies** is *High*, IF **Inventory days on hand** is *Average*, IF **Storage Equipment** is *High*, THEN **Storage Flexibility** is *About High*.

As it is possible to analyze in the previously fuzzy rules, the only difference between the first example and the second is just in the factor Location and cube occupied where the grade change from *High* to *Low*. This has a considerable influence in the final storage flexibility result, a changing from *High* to *About High.*

The problem that derives from this example is the number of fuzzy rules that is necessary to write to define the entire framework without any lack of information or result. To each main stage of the warehouse, all the possibilities (fuzzy rules) have to be written, one-by-one. This makes it really extensive and time consuming. In the case of the main group "storage" been selected, we just have four different factors, and it is still extensive. To be more precise, in this case with just four factors to be analyzed, each one of them with five MF, we have to write 625 rules to have a complete work without gaps. But in the case of for example, "receiving", there are six factors. This even raises more the number of necessary fuzzy rules to define the entire program, to a number of 15625 rules to write.

If we look with attention, with this type of evaluation and description written before, it is even possible to declare that we are already simplifying the framework, because in the simplest and purest way, all of the factors belonging to the different main six different groups could be organize in various rules. In this last possibility we will have in the same fuzzy logic rule, thirty-five factors, each one of them with the respective grade. This will raise even more the number of indispensable rules to write a successful framework, without failing in some assessments. The precise number of fuzzy rules in this case it will be $2.910383 \times 10^{24}$.

There are different solutions to get around these problems, that due to some circumstances, cannot be approached in this thesis. There is more information regarding this topic in the section 4.1.

Facing this problem, and finding a solution that can withstand with time limitation of these thesis, another solution appear. Between six different main groups we had 35 different factors. Realizing that was impossible to develop a program that could work with all the factors, a selection between the most important factors had to be made.

Since the beginning of this thesis, the warehouse processes were divided into 5 main groups. Now, the selection will pass through those groups. It is necessary to choose two or in the maximum three different groups. These main groups are selected regarding the importance of each one of them in the overall warehouse process.

Then for each one of the factors that were previously chosen it is necessary to choose the best linguistic values for them. The example state before with *Low*, *About Low*, *Average*, *About High* and *High* is not the best evaluate representation for all the factors. For some of them, maybe just values, as *Low*, *Average* and *High* are enough to define the factor. With this reduction of factors and linguistic values is possible to write fuzzy rules one by one, even being an extensive process.

To further research about the possibility of doing more related with fuzzy logic approach you should consult the topic present in this thesis "Work improvements". In this topic are presented more options, but due to different reasons explained there, the simplification process described before was chosen.

### 3.3.1 Used Factors Explanation

After some reflection about the importance of each of the main stages the selection was not easy. The difficulty in the selection is when trying to represent different kinds of warehouses in the same framework. For some warehouses the receiving stage could be more important than the one of pick-n-pack.

Further research indicates that it is possible to select two main stages that are crucial for all warehouses. Receiving and pick-n-pack.

Receiving for the reason of being the first stage within the warehouse, and so responsible for the initial success of the entrance of goods. If this first stage is not well implemented all the next stages will turn out to be a chaos.

Pick-n-pack by different reasons. It is the first stage where the warehouse appears in front of the customers. When goods are ordered, this is the first phase. It is also the stage with more related costs, as it is shown in the next Figure 3.1. Can be or not fully automated depending of the goal or capability of the warehouse.

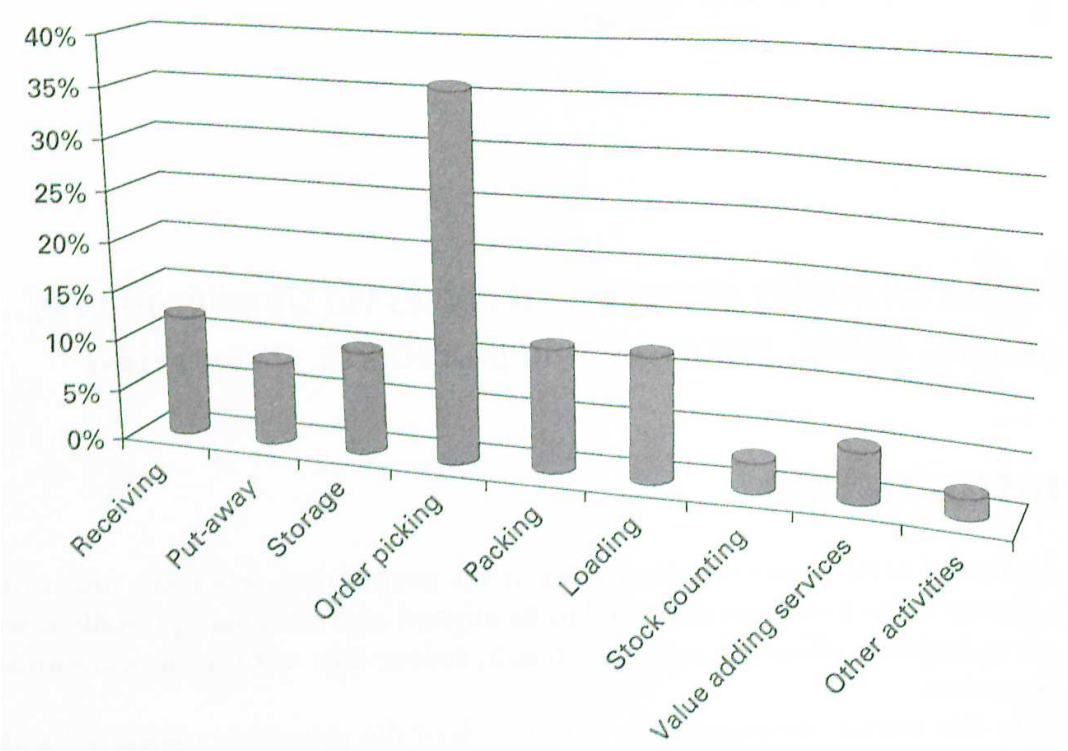


**Figure 3.1- Warehouse activities as a percentage of total cost [Richards 2011, p. 44]**

In the next Figure 3.2 it is shown the percentage of the costs shared through the warehouse main stages. The stages with more related costs should be the ones with more attention to improve.

Having selected the main stages that should be part of the assessment after simplification of the process is time to select the linguistic values that will represent each one of the factors correspondent to receiving and pick-n-pack.

Above all, is necessary to remember that the linguistic values are associated with the

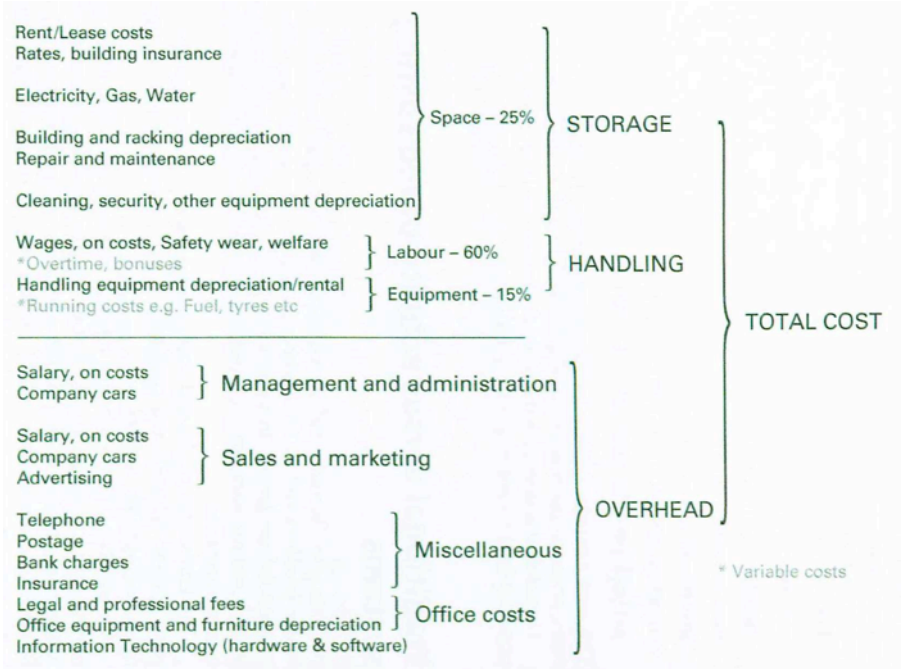


**Figure 3.2- Simple warehouse cost tree**

description made before in this paper (chapter 2.6).

In the following section it is possible to understand the linguistic values attributed to each one of the factors, and further explanation.

Regarding the Table 3.1 is possible to identify all the linguistic values attributed to the factors belonging to the main group receiving.

**Table 3.1- Linguistic Values Receiving Factors**

| **Receiving** | |
|---|---|
| **Factors** | ***Linguistic Values*** |
| Volume received | *Low / Average / High* |
| Homogeneous vs. Heterogeneous | *One / Both* |
| Receiving dock-door utilization | *Low / Average / High* |
| Compliance labeling | *Bad / Average / Good* |
| Location control | *No / Yes* |
| Material handling equipment | *Discord / Agreed* |

Volume received will be characterized as *low*, *average* or *high*. A warehouse that is capable of receiving a large amount of goods at the same moment is considered positive and better than the one that have everything completely scheduled and planned to work well. A warehouse capable of receive a large variety of goods simultaneously without becoming congested is attributed the *high* value. For the opposite is considered the *low* value. The *average* value should be chosen when is presented a mix of low and high volume quantity received.

Concerning homogeneous and heterogeneous factor, remember the meaning of such characteristics explained in the specification part (chapter 2.6) included in this paper. It is easy to understand how a warehouse capable of handling and treating heterogeneous amounts of goods is more flexible than the one that prefers to treat just one type or model of product per pallet received. The warehouse capable of handling heterogeneous goods is also capable of handling in 22 of the simplest way, homogeneous. So, choosing the linguistic value *one* means that the receiving phase is just capable of treat homogeneous goods. For *both* we are in presence of a flexible system, and so the most positive choice.

For receiving dock-door utilization factor, the *high* value represents the dock-door that is being well managed. It doesn't depend on the numbers of doors present in the warehouse. A *low* value shows a bad management of them. The *average* value represents the average dock-door management.

Compliance labeling is *bad*, *average* or *good*, depending on the facility or complexity of understanding the information in the label, respectively.

This next factor, location control is present in almost all the main stages of this work. To have flexibility within the warehouse is paramount to know every time where are the goods in the warehouse. If a warehouse is capable to have that information, a value *yes* is attributed, if not the opposite, a *no*.

Material handling equipment besides location control is also in all the main stages. The advantages and disadvantages depend on the goal and objectives of the warehouse managers. So it is always necessary to possess previous information about the targets of the company before starting with the assessment. As we discuss before, a warehouse technology fully equipped is not the best regarding flexibility parameters. A compromise is necessary, and so it is mandatory to understand the aim of the company beforehand. If the analyzer agrees with the usage of the handling equipment, regarding the aims and targets of the warehouse so *agreed* is the value. If the material handling equipment is not consistent with the company's aims, so *discord* is the value.

Considering the following Table 3.2 we can observe the factors regarding the pick-n-pack stage and the respective linguistic values.

**Table 3.2- Linguistic Values Pick-n-pack factors**

| **Pick-n-pack** | |
|---|---|
| ***Factors*** | ***Linguistic Values*** |
| Orders picked | *Low / Average / High* |
| Picking labour vs. Equipment utilization | *Discord / Agree* |
| Picking accuracy | *Low / Average / High* |
| Order picker cycle time | *Bad / Average / Good* |
| Picking documentation | *Bad / Good* |
| Material handling equipment | *Discord / Agree* |

The first factor, orders picked, is the number of orders picked per determined time. A *high* value or orders picked is a result of better efficiency and so in this case more flexibility above all when the warehouse system is under stress. Speed and accuracy are the keys to achieve the success. A *low* value represents a bad picking system, incapable of dealing with oscillating orders. An *average* receiving is a sign of a normal picking system.

Picking labor vs. equipment utilization is another factor where it is necessary to observe with attention to the warehouse picking system. An abuse of equipment can certainly be more efficient than picking labor but less flexible. It is necessary to understand the balance between picking labor and equipment utilization is the best to achieve a higher parameter of efficiency. If the analyzer concurs with the balance used in the warehouse; *agreed* is the value, the opposite for *discord*.

*High, low* or *average* attributes to picking accuracy are directly attributed. If the warehouse presents a good or *high* picking accuracy, it is *high* value and the opposite for *low* value. Medium values of picking accuracy belong to *average* value.

Concerning order picker cycle time, the lowest is the best. In this case, a *good* value should be attributed. For a bad or long order picking time, the *bad* value should be considered. For an option in the middle, *average* value.

The picking documentation should be clear and obvious for everyone. So, when the documents are enlightened, *good* value is the correct choice. If it is difficult to interpret, it is *bad* value.

Material handling equipment follows the same explanation as the one for the receiving stage explained before.

After the overall assessment the main objective is to get a result for the warehouse flexibility. For that it is also necessary to attribute membership functions with linguistic values to the final results of the evaluation.

## 3.4 Fuzzy Logic Program Development

To understand the warehouse flexibility assessment program it is necessary to comprehend how the Matlab Fuzzy Logic toolbox works. For that it is fundamental to know the main interfaces that this toolbox can present. It is also required to apprehend everything that is possible to do in one interface or window, it will change or affect something in the others windows. A change made in one window will interfere in all the systems.

In the this toolbox it is possible to identify five different interfaces:

- Fuzzy Inference System (FIS) Editor - the main editor or menu. Number of inputs and output variables, their names can be customized in this editor. The number of inputs is unlimited by the software. The only constrain is the available memory of the machine/computer. If the number of inputs is too large, or the number of Membership Functions (MF) is too big, then it may be difficult ultimately to analyze the inference results.
- Membership Function Editor - by the FIS editor it is possible to access to the MF editor, where all the MF shapes are defined associated with each variable.

- Rule Editor - interface where it is possible to define and edit all the fuzzy rules that will determine how the system analyzes the inputs inserted previously.
- Rule Viewer - belongs to the analysis of the results. Here it is possible to analyze how the system is comprehending the fuzzy rules through the view of MF influence and consequently in the output graphics. It is often used as a diagnostic interface.
- Surface Viewer - through a plot view it is possible to view the relation between inputs and outputs. Surfaces generated that represent the system have some limitations when facing large number of inputs, where the visualization becomes less important due to the large number of factors that take in consideration for the final result. In this case it is just possible to see the influence of two inputs and one output at the same time, due to view dimensions limitations (3D).

All these editors and viewers interfaces are part of the used and general GUI tools, graphical user interface. In the next Figure 3.3 it is possible to take a general view to all the interfaces referred before.

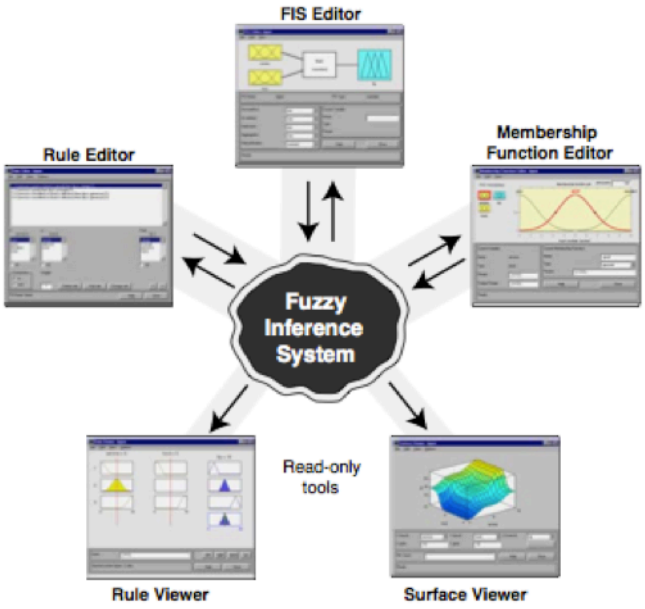


**Figure 3.3- Graphical User Interfaces [The MathWorks 2014, p. 2-35]**

### 3.4.1 FIS Editor

When opening the FIS Editor window for the first time, some sets are already set. Following the Figure 3.4 that is presented next it is possible to see the names of each input variable (yellow box) on the left, and the output variable (blue box) on the right. It is important to refer that the MF presented in the input and output boxes are just samples that don't represent the actual MF shapes, this is through the entire program development.

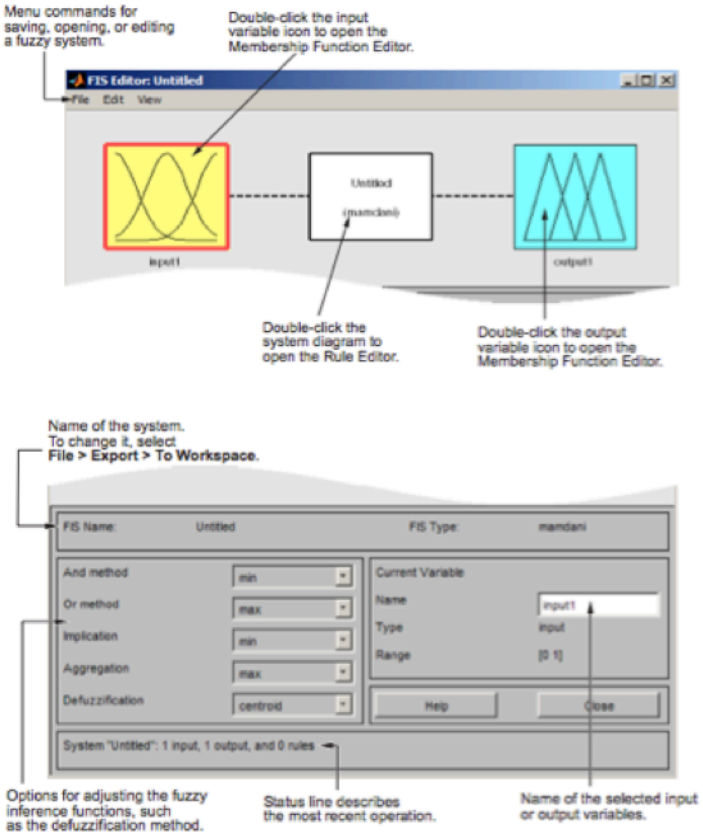


**Figure 3.4- FIS Editor Example [The MathWorks 2014, p. 2-38]**

In the white box shows the name of the system and the type of inference used. In this assessment the type of inference used is the default Mamdani-type inference. Another type of inference exists, Sugeno-type inference, but the first one was the best option as it will be possible to understand during the following steps of the work.

In our specific case, it was necessary to develop two different programs that will ultimately work simultaneously. One for Receiving and the other to Pick-n-pack stage. In each of them the inputs inserted were the factors collected previously, such as volume received, dock-door utilization, etc. In each of the stages were selected six factors that better assess the flexibility in that warehouse stage. With this, it was necessary to define six inputs and one output for each program. Being the outputs, the

receiving flexibility and the pick-n-pack flexibility respectively, as it is possible to verify in the next Figures 3.5 and 3.6.

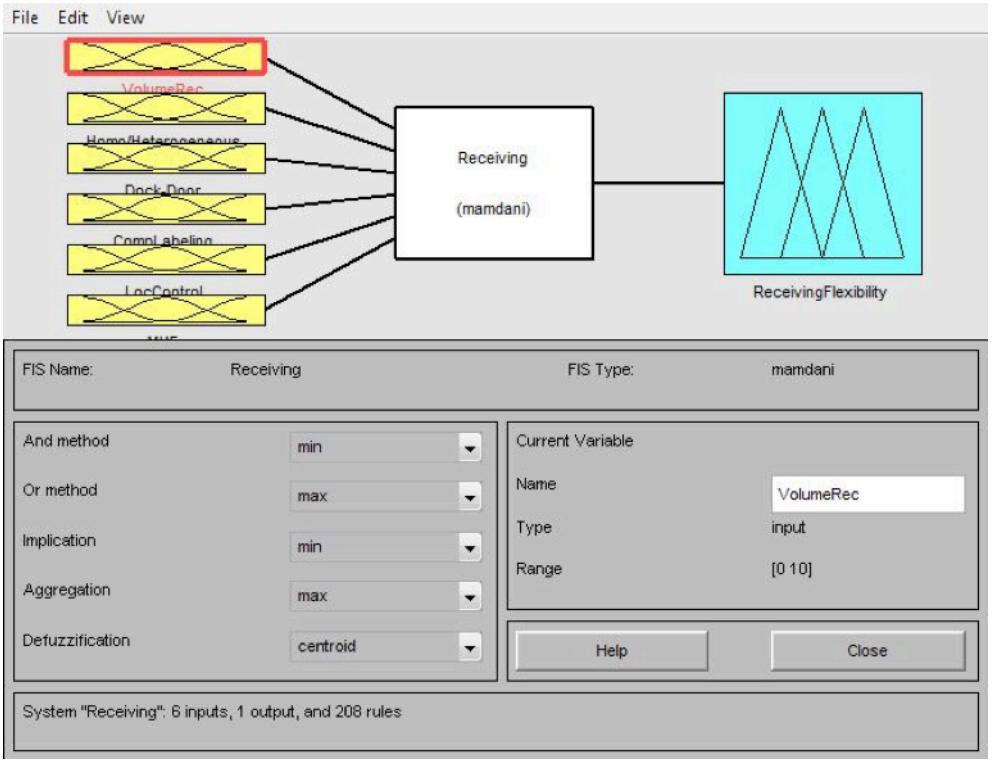


**Figure 3.5- Receiving FIS Editor**

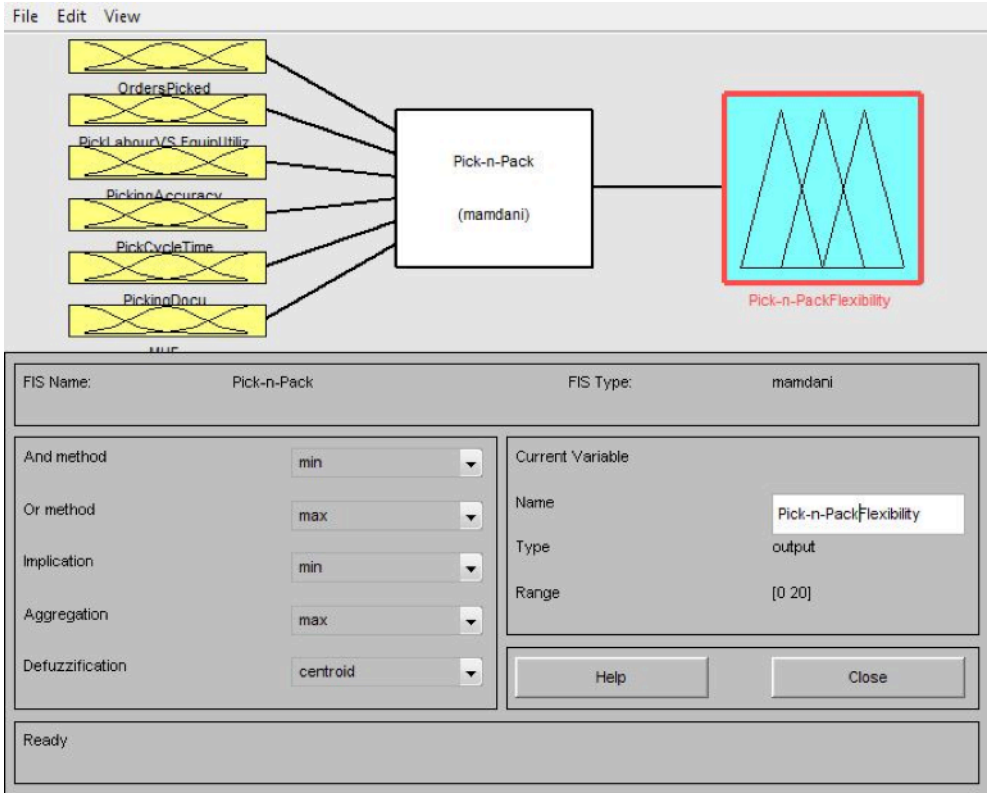


**Figure 3.6- Pick-n-Pack FIS Editor**

After this brief explanation of the FIS editor, still some information is missing. Perhaps the most important and necessary one to refer to is the deffuzification, because it makes part of the essence of the fuzzy logic.

"*Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned.*" by Zadeh [Zadeh, web].

The last pop-up menu on the low left ("Defuzzification") of the previous Figures 3.5 and 3.6, gives us the option of two different inference modes.

There are so, two different types of inference systems available with the Matlab fuzzy logic toolbox, the standard Mamdani and Sugeno-type. "*Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory.*". [The MathWorks, 2014 p. 2-21] These two inference system types differ in a practical point of view in the way outputs are determined. It is possible to enumerate advantages of each one of them. [The MathWorks, 2014 p. 2-107]

Advantages of the Sugeno Method:

- It is computationally efficient;
- It works well with liner techniques (e.g., PID control);
- It works well with optimization and adaptive techniques;
- It has guaranteed continuity of the output surface;
- It is well suited to mathematical analysis.

Advantages of the Mamdani Method:

- It is intuitive;
- It has widespread acceptance;
- It is well suited to human input;

After knowing the advantages of each of the inference types, and testing the Mamdani method with good results, ultimately this was the best choice.

### 3.4.2 Membership Function Editor

"*A MF is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1.*(…) *The function it self can be an arbitrary curve whose shape can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency*." by Zadeh. [Web]

The MF editor is the interface where it is possible to create, change and modify all the MF that are necessary for the work. One more time is necessary to refer that all the MF are associated with all of the input and output variables for the FIS.

In this interface a large pallet of options regarding the MF is available to customize. Type, name, parameters that define the shape of MF, etc, are among others some settings that can be set in this window.

"*The fuzzy logic toolbox includes eleven built-in MF types. These eleven functions are, in turn, built from several basic functions: piecewise linear functions, Gaussian distribution function, sigmoid curve, and quadratic and cubic polynomial curves. (...)The simplest membership functions are formed using straight lines(...)*".[Zadeh, Web]

The process of choosing the best MF that better defines our goals depends on the problem that is presented and the available research data. There are two different ways to select the MF. If we have access to a prior knowledge about the shapes of the MF's that define what we want to study (e.g. from histograms on sampled data), then it is easier to find the best MF that defines the real factor. In these cases, the MF will be very similar to the shape of the information that we possess.

On the other hand, there is a second method. We could start with one of the most simple functions, for example, triangular or trapezoidal shapes that are easy to implement and fast to compute, being efficient and simple. In both cases, the end of defining the best functions should always be a tuning a fitting process to try to get an accurate result and more importantly to always put the working program as the real system that is being studied.

In order to make the best MF choice, a large amount of experience is needed in a given situation. This experience will tune up and best fit the MF selection. In most of the cases a high fidelity intuition based on sufficient experience, will give an acceptable answer. All the first attempts should start with the simplest shapes, based in straight lines. Thus if the system is not transcribing the real system, changes should be made.

As it was said earlier it always depends from system to system. For example, while some MF can take values between 0 and 1, it may be interesting to allow some of them to never reach 1, in order to represent information that is never certain. [The MathWorks, 2014 p. 2-6]

After reflection and most of all due to the lack of a prior information or data available to compare and serve as a base to this work, we will begin with triangular membership functions shape and take in advantage all the points previously referred.

Finally, in the work there were two different types of MF used, triangular and trapezoidal. These two distinct shapes are represented in the Figure 3.7, as an example. With this choice we had simplicity and efficiency to the assessment.

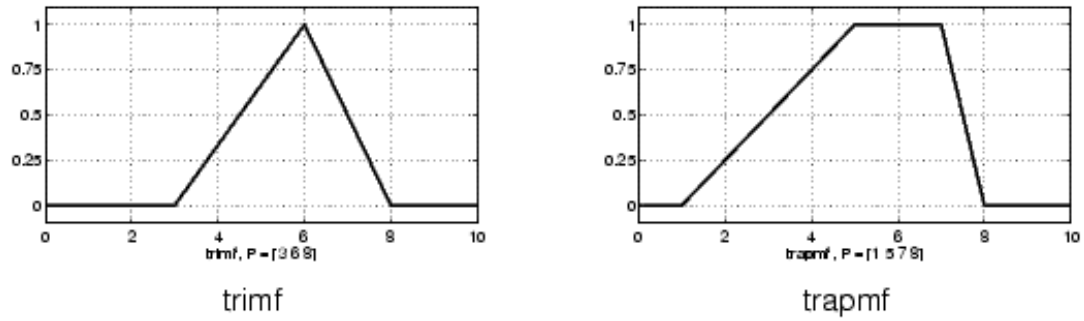


**Figure 3.7- Triangular and Trapezoidal MF shapes [Zadeh 1995, web]**

In the next Table 3.3 is possible to analyze which kind of MF were used for each of the input factors.

**Table 3.3- Relation between MF shapes and factors**

| | **Receiving** | **Pick-n-Pack** |
|---|---|---|
| **Triangular** | -Volume received<br>-Dock-door utilization<br>-Compliance labeling | -Orders picked<br>-Picking accuracy<br>-Order picker cycle time |
| **Trapezoidal** | -Homogeneous vs. Heterogeneous<br>-Location control<br>-MHE | -Picking Labour vs. Equipment utilization<br>-Picking documentation<br>-MHE |

In this stage, and making the relation to other part of this work (3.3.1 - Used Factors Explanation) were established different linguistics values to each of the different factors.

In the next four figures (Figures 3.8, 3.9, 3.10, 3.11) it is possible to analyze in detail the types of triangular and trapezoidal curves that better describe the warehouse evaluation. It is necessary to remind that these four figures are just two examples for receiving and pick-n-pack stages triangular and trapezoidal shapes.

The follow Table 3.4 shows the parameters used in all the curves shaped. It is necessary to refer that all the inputs have a range of [0-10].

**Table 3.4- MF Parameters shapes**

| | **Low** | **Average** | **High** |
|---|---|---|---|
| **Triangular** | [0 0 4] | [0.5 5 9.5] | [6 10 10] |
| **Trapezoidal** | [-2.7 -0.3 4.99 5] | ———————— | [5 5.01 10.2 11] |

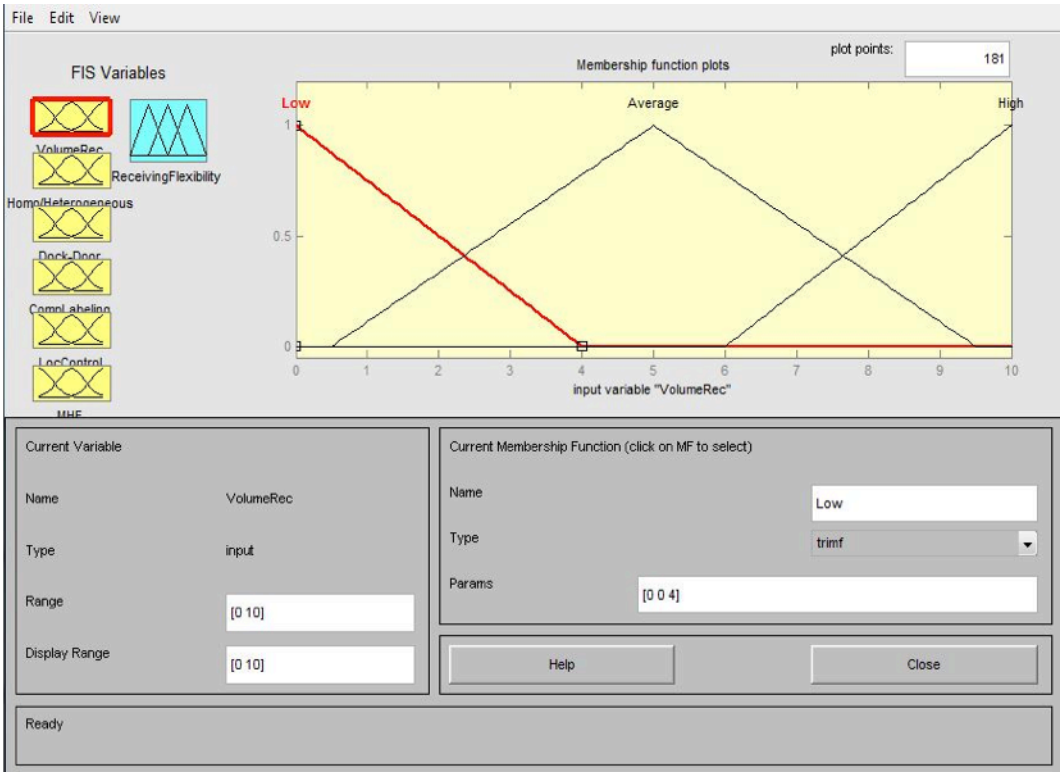


**Figure 3.8- Volume Received MF (Triangular Example)**

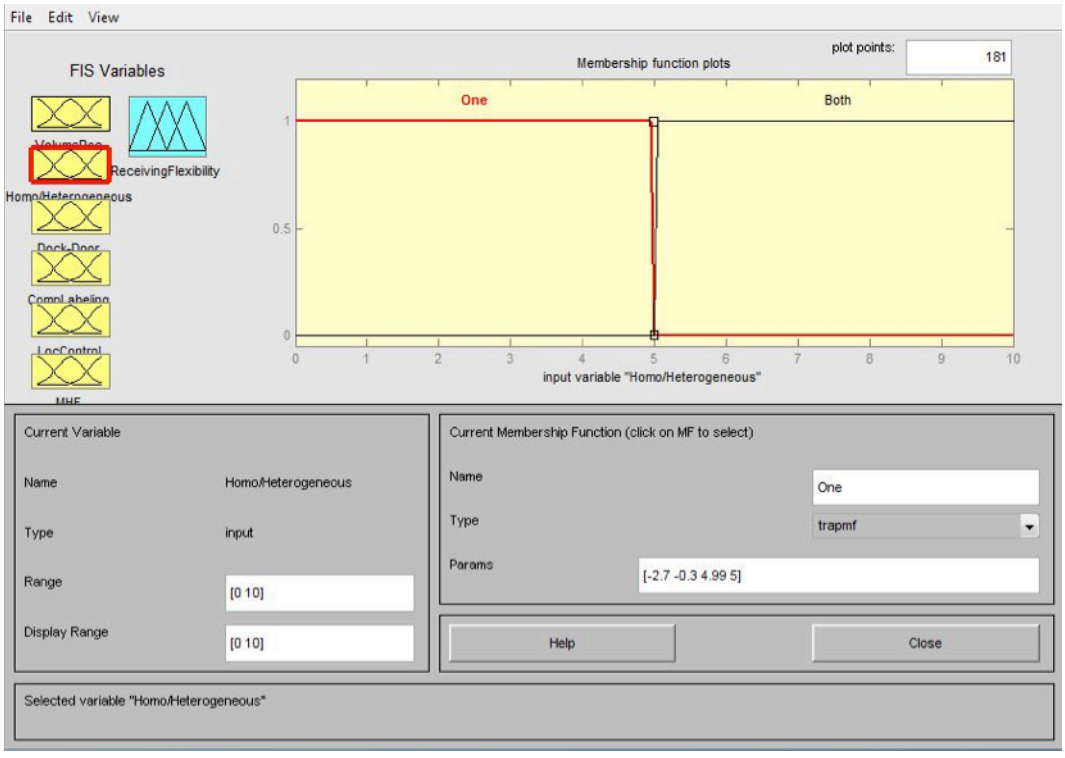


**Figure 3.9- Homo/Heterogeneous MF (Trapezoidal Example)**

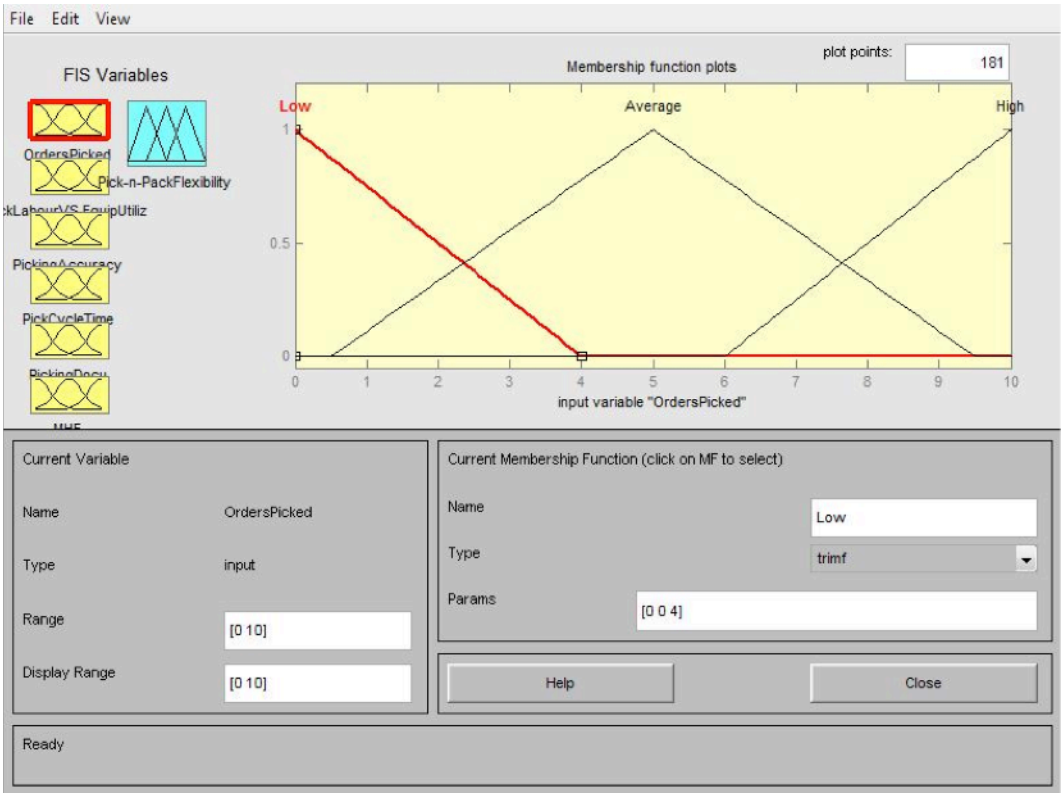


**Figure 3.6- Orders Received MF (triangular Example)**

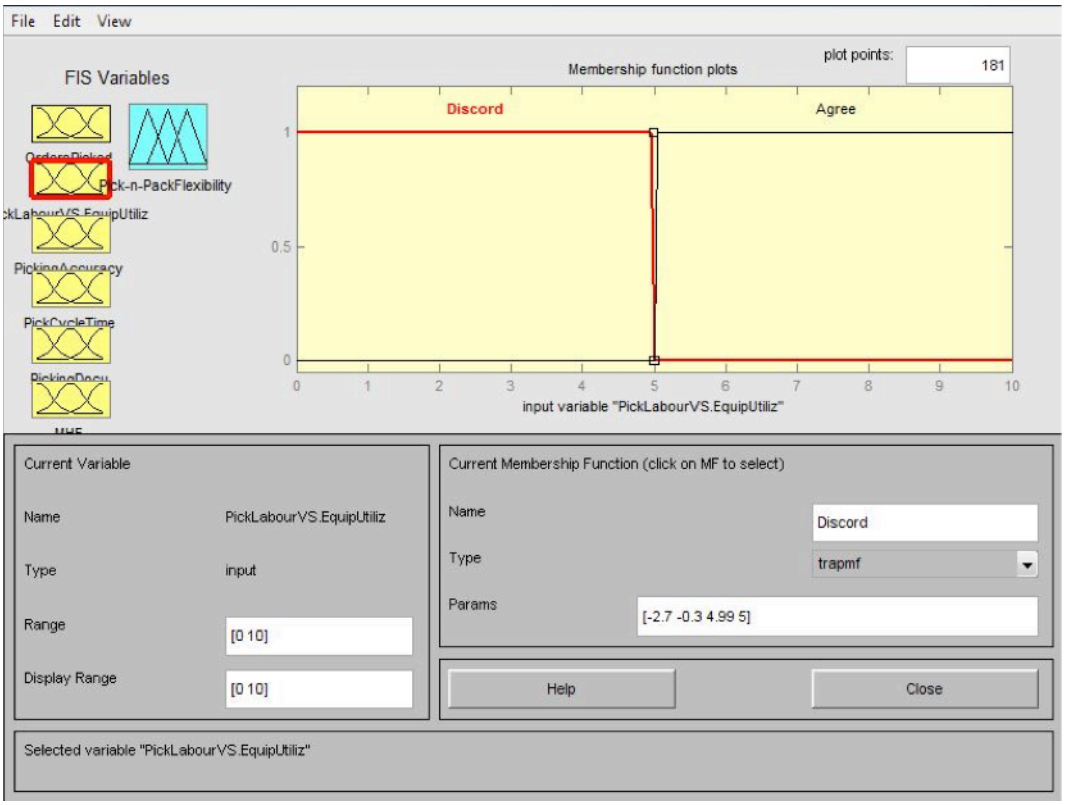


**Figure 3.5- Picking Labour vs. Equipment Utilization MF (trapezoidal example)**

As it was explained in the Work Simplification section of this work, some factors just have two options of evaluation, such as the factor “Homogeneous vs. Heterogeneous” in the receiving stage. This among others belong to the trapezoidal MF, and that is the reason to shape of the curve, where an average input as 5, doesn't correspond to the reality. The extremes of the range [0-10] have to be taken in this case.

The follow Figures 3.12 and 3.13 shows the MF that was drawn for the output results used next to the defuzzify of results. The outputs differ from the inputs in the range, from [0-20].

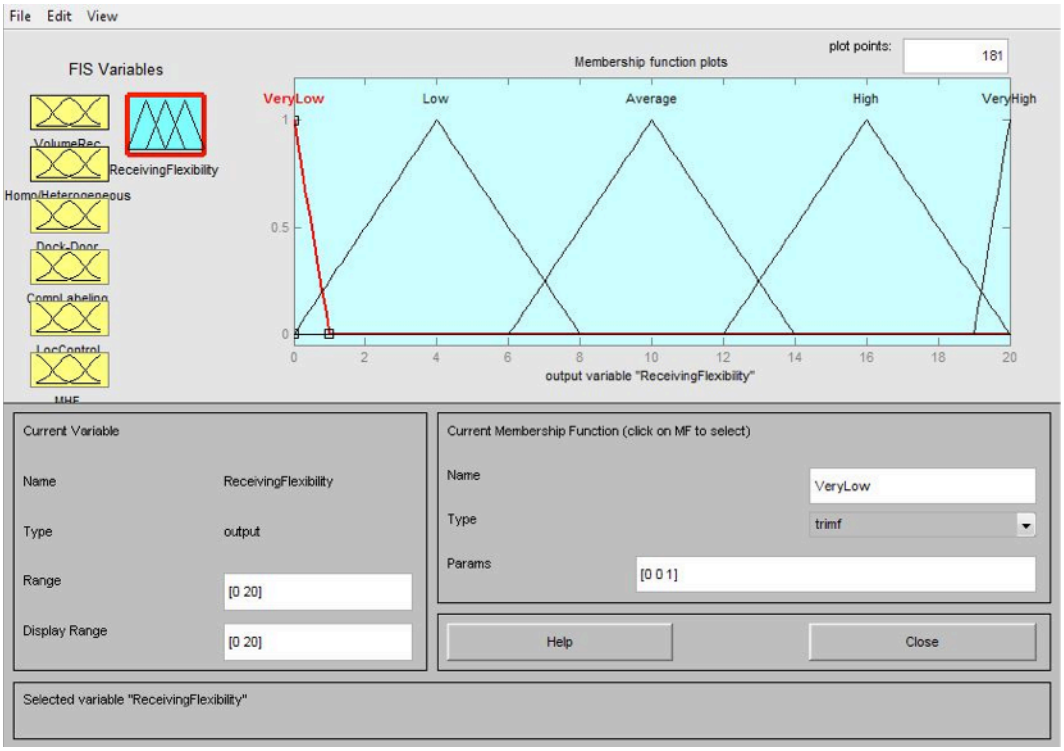


**Figure 3.7- MF Receiving Flexibility Output**

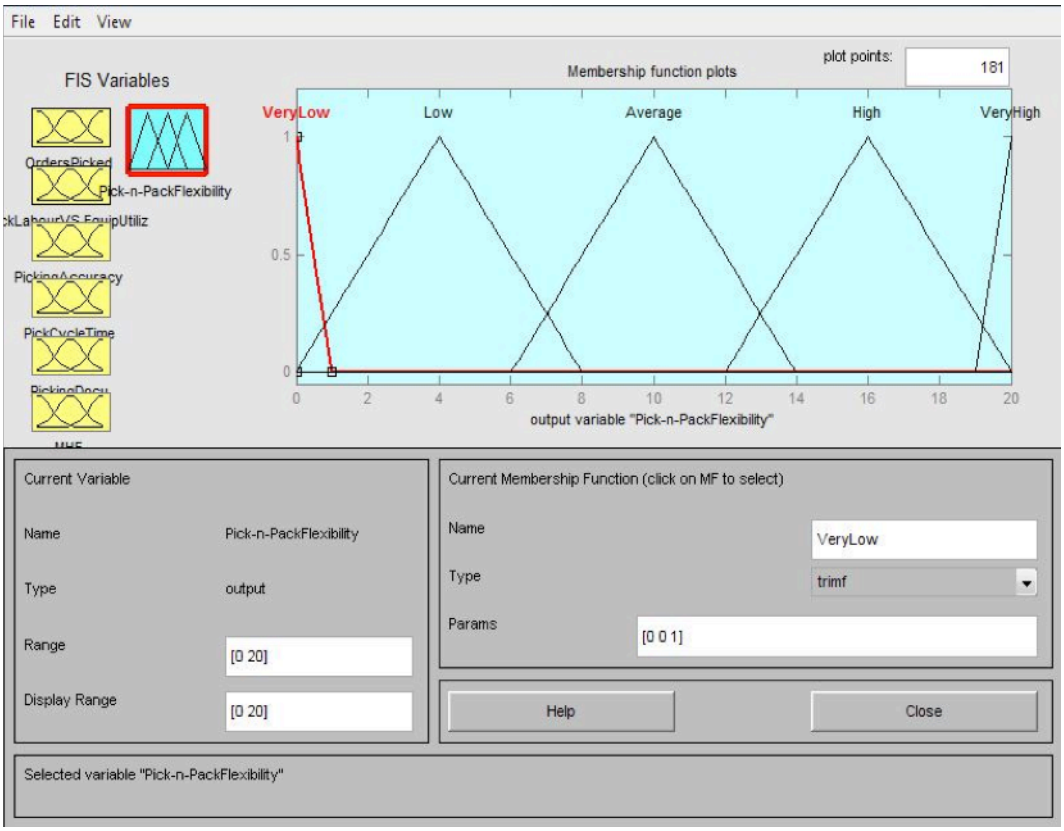


**Figure 3.8- MF Pick-n-Pack Flexibility Output**

The follow table 3.5 shows the parameters used in the output MF shapes.

**Table 3.5- Parameters used for Output MF**

| | Very Low | Low | Average | High | Very High |
|---|---|---|---|---|---|
| **Triangular** | [0 0 1] | [0 4 8] | [6 10 14] | [12 16 20] | [19 20 20] |

### 3.4.3 Rule Editor

"*Constructing rules using the Rule Editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS editor, the rule editor allows you to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box, and one connection item. (...) Rules may be changed, deleted, or added, by clicking on the appropriate button.*" [Fuzzy Logic Toolbox User's Guide 2014]

These rules are made through IF-Then basis. The essence of this process is explained in the fuzzy logic section 3.3 of this work.

At this point was where the simplification referred in the chapter 3.3 of this work had to appear. Concluded from that section, it would be impossible to write all the fuzzy rules to join all the factors in one complete and extremely efficient flexibility assessment program. That is the reason why we ultimately opted by the simplification, ending just with the two most important stages associated with flexibility. For each stage, 208 rules were written to define all the possibilities of a warehouse assessment. With this all the assessment situations will have an answer. Due to the extensive list of fuzzy rules written we finished getting an evaluation program without lacks of information.

In the next figures (3.14, 3.15, 3.16, and 3.17) are shown a list rules example, being the first one about the receiving stage and the next about pick-n-pack main stage..

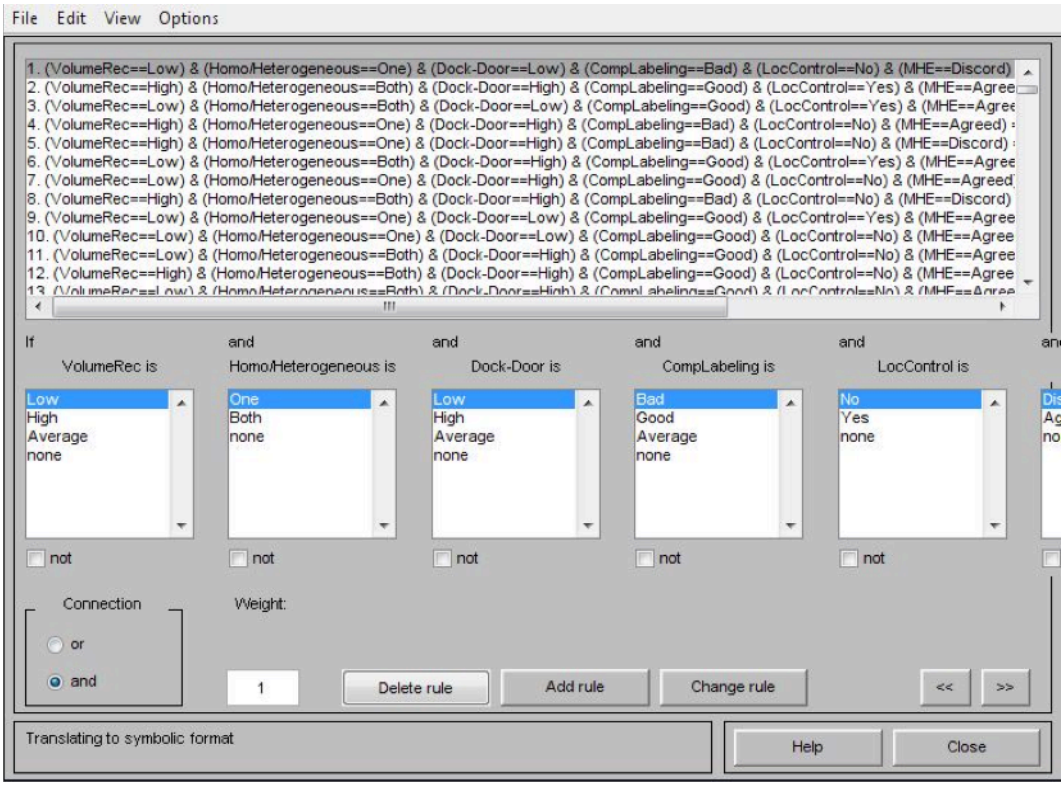


**Figure 3.9- Rule Editor**

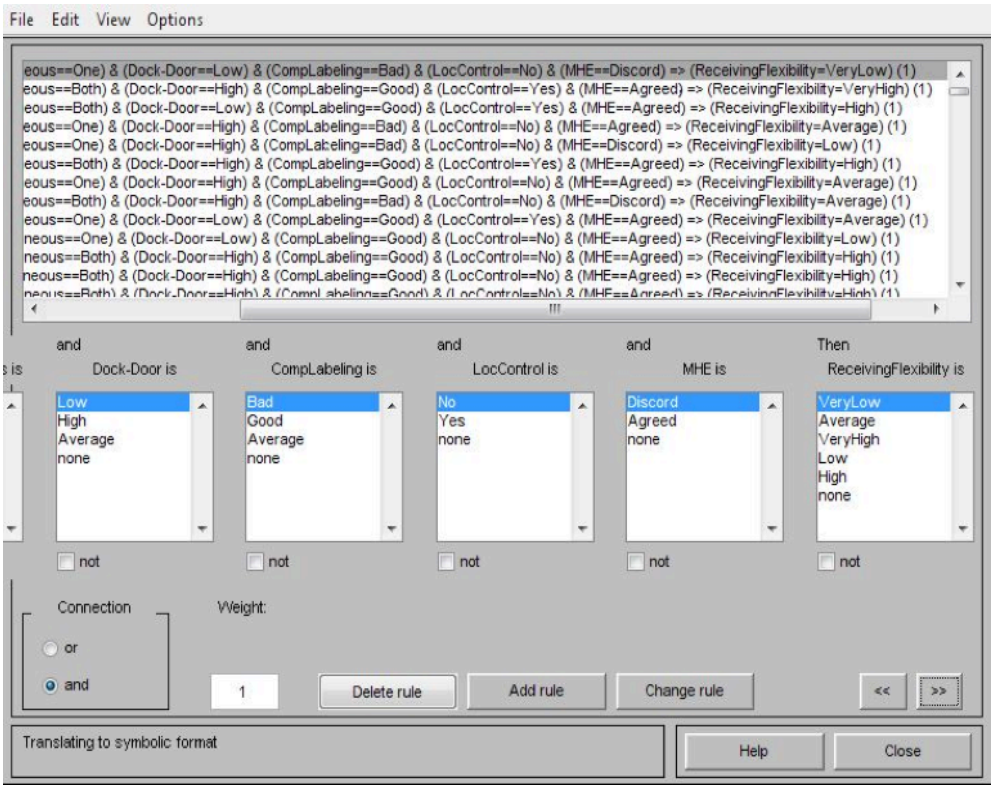


**Figure 3.10- Receiving Rule Editor (2)**

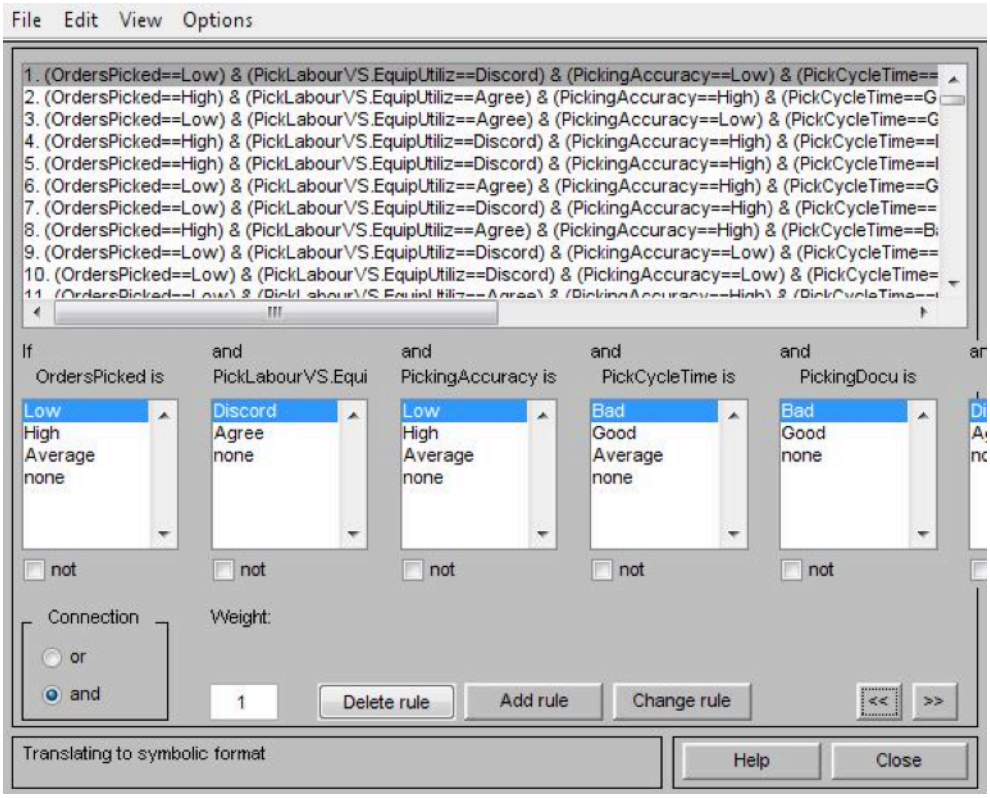


**Figure 3.11- Pick-n-Pack Rule Editor**

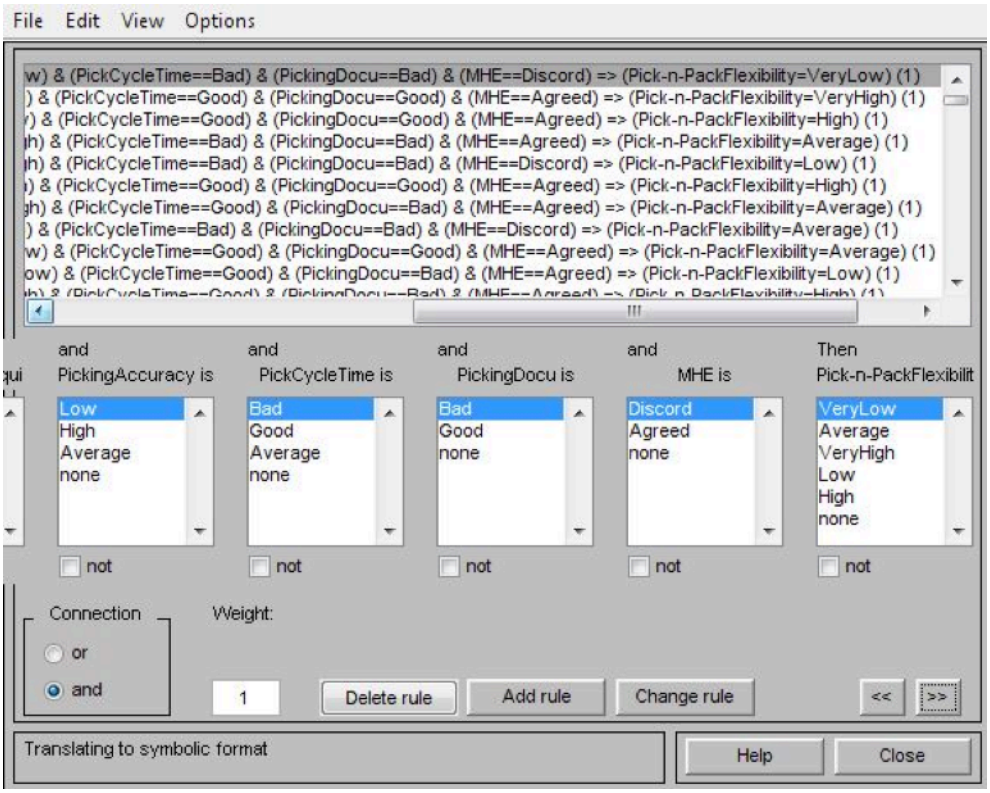


**Figure 3.12- Pick-n-pack Rule Editor (2)**

In order to construct all the fuzzy rules that were referred before, a scheme was developed to help define the output MF between different MF inputs. As it is possible to analyze in the next table 3.6 the first row of the table, has all the output MF defined in the system (Very Low, low, etc.). The upside or downside arrows represent positive or negative aspects of the input factors. The horizontally arrow, represent a case where it is neither positive nor negative, but average.

**Table 3.6- Descodification of Output Values**

| Very Low | Low | Average | High | Very High |
|---|---|---|---|---|
| ↓↓↓↓↓↓ | ↓↓↓↓↓↑ | ↑↑↑↓↓↓ | ↑↑↑↑↑↓ | ↑↑↑↑↑↑ |
| ↓↓↓↓↓↔ | ↓↓↓↓↑↑ | ↑↑↑↓↓↔ | ↑↑↑↑↓↓ | ↑↑↑↑↑↔ |
| | ↓↓↓↓↑↔ | ↑↑↓↓↓↔ | ↑↑↑↑↓↔ | |
| | ↓↓↓↓ ↔ ↔ | ↑↑↑↓↔↔ | ↑↑↑↑↔ ↔ | |
| | ↓↓↓↔ ↔ ↔ | ↑↓↓↓↔↔ | ↑↑↑↔ ↔ ↔ | |
| | | ↑↑↓↓↔↔ | | |
| | | ↑↑↓↔↔↔ | | |
| | | ↑↓↓↔↔↔ | | |

Signs Legend Table 3.6:

↑ - High / Both / Yes / Agree / Good (positive aspects)

↓ - Low / One / No / Discord / Bad (negative aspects)

⟷ - Average aspects

To better understand how the output values were taken, it is better to present an example. By choice the 13th rule for the Receiving program was the chosen. The next table 3.7 shows the reasoning for the final output value.

**Table 3.7- Example of descodification for Receiving**

| Factors | Linguistic MF values | Rule 13th (Receiving) | Arrows | Output MF |
|---|---|---|---|---|
| Volume Received | Low / Average / High | Low | ↓ | ↑↑↑↑↓↓ = High |
| Homogeneous vs. Heterogeneous | One / Both | Both | ↑ | |
| Dock-door utilization | Low / Average / High | High | ↑ | |
| Compliance Labeling | Bad / Average / High | High | ↑ | |
| Location Control | No / Yes | No | ↓ | |
| MHE | Discord / Agree | Agree | ↑ | |

At this point, the fuzzy inference system has been completely defined. In that the variables, membership functions, and the rules necessary to calculate the receiving or the pick-n-pack flexibility are in place. "It would be nice, at this point, to look at a fuzzy inference diagram (…) and verify that everything is behaving the way we think it should. This is exactly the purpose of the Rule viewer (…)." by Zadeh (1995).

### 3.4.4 Rule Viewer

"*The rule viewer displays a roadmap of the whole fuzzy inference process. (...) Each rule is a row of plots, and each column is a variable. The yellow plots show the MF referenced by the antecedent, or if-part of each rule. The blue plots show the MF referenced by the consequent, or then-part of each rule.(...) The last plot in the last*

*column represents the aggregate weighted decision for the given inference system. This decision will depend on the input values for the system*" by Zadeh (1995).

To interact with the program it is quick and simple. In the interface lower left there is a text field into which you can insert input values. Since there are six different inputs, and the range of the MF previously defined and explained is from [0-10], the input values can be in the form [6 2 3 7 8 9], for example. It is also possible to adjust these input values by clicking anywhere directly on any of the six plots. This action will move the vertical red line horizontally, to the clicked point. In any of these actions a new calculation and consequently a new value will appear after the fuzzy inference process takes place. "A yellow patch of color under the actual MF curve is used to make the fuzzy membership value visually apparent. Each of the characterizations of each of the variables is specified with respect to the input index line in this manner. The aggregation occurs down the last column, and the resultant aggregate plot is shown in the single plot to be found in the lower right corner of the plot field. The dufizzified output value is shown by the thick line passing through the aggregate fuzzy set." by RADIO. As it is possible to observe in the next figures 3.18 and 3.19, it was made as an experience with the parameters [8 8 8 8 8 8]. The final receiving flexibility value was of 16,5 in a range between [0-20], as was referred previously in the MF section.

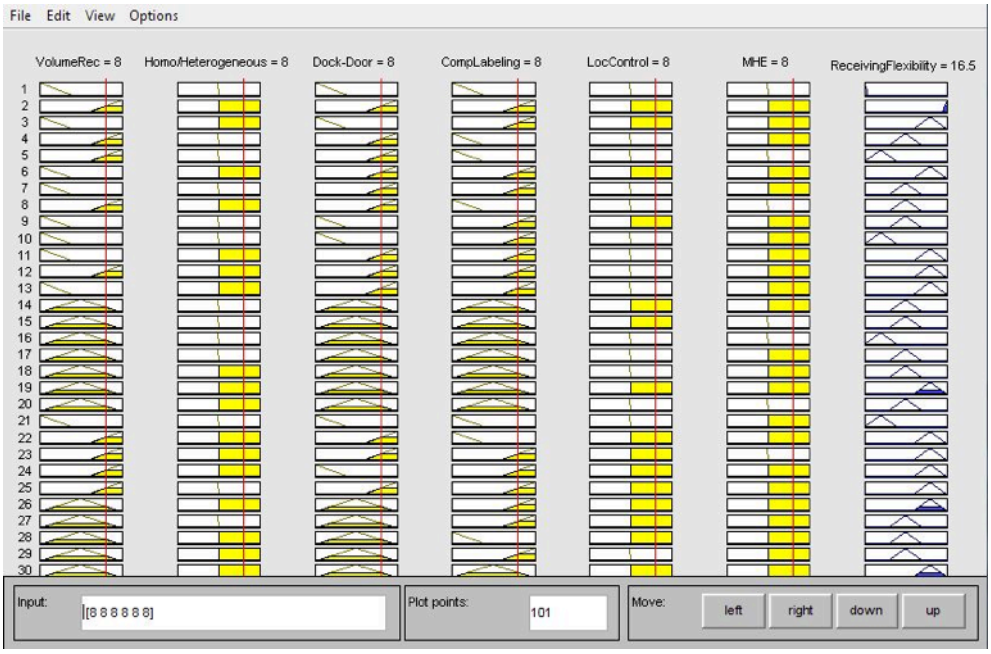


**Figure 3.13- Rule Viewer for [8 8 8 8 8 8] Receiving Input**


**Figure 3.14- Rule Viewer for [8 8 8 8 8 8] Receiving input (2)**

The advantage of the rule viewer is that it allow us to interpret the entire fuzzy inference at once. In other words, with this interface it is possible to observe in real time the influence that each one of the inputs and rules have in the final result. Within this, the rule viewer shows how the shape of certain MF influences the overall result. "*Since it plots every part of every rule, it can become unwieldy for particularly large systems (...)*." as our case is. There are some setbacks that appear with the large systems, such as the time to compute the inference, and the difficulty to move the rule viewer up and down. This movement is important, since developing the systems it is constantly necessary to check how and what is being performed. Monitor the systems is paramount.

"*The rule viewer shows one calculation at a time ad in great detail. In this sense, it presents a sort of micro view of the fuzzy inference system*." by Zadeh.

### 3.4.5 Surface Viewer

"*The surface viewer has a special capability that is very helpful in cases with two (or more) inputs and one output: you can actually grab the axis and reposition them to get a different three-dimensional view on the data.*" [Zadeh, 1995 web]. When facing problems to generate plots with two-input one-output systems, this interface is really useful, to get an overall idea how the system will react in case of changing parameters. "*When we move beyond three dimensional overall, we start to encounter trouble displaying the results*." by RADIO. Since, in our study case we have six inputs, that would mean a six-dimensional plot, but computer monitors cannot display a five-dimensional shape. Even, with this overwork of inputs for fuzzy logic toolbox it is possible to select the inputs and outputs for plotting. Having all the time to monitor

limitation of three-dimensional display.

In the next examples showed by the next figures 3.20 and 3.21 it is possible to analyze two plots, made more by curiosity reasons than for results, since it is impossible to analyze all the system at once..

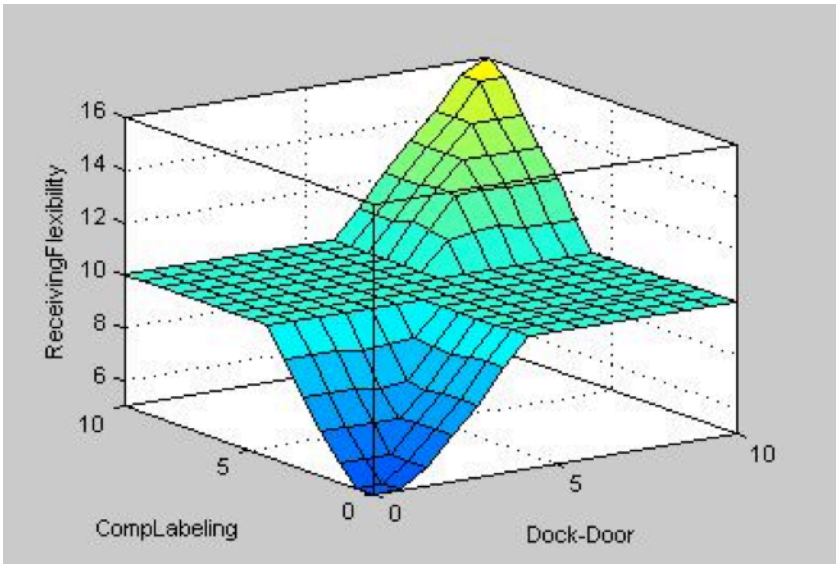


**Figure 3.15- Rule Viewer Example**

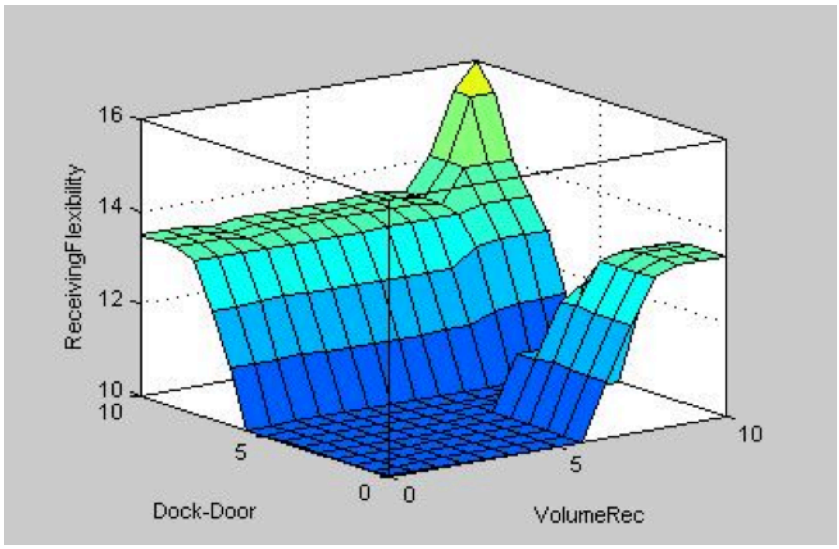


**Figure 3.16- Rule Viewer Example (2)**

## 3.5 Overall Resume Steps

After all, it is possible to enumerate the fundamental parts of fuzzy logic toolbox in the following steps:

- Fuzzify inputs
- Apply fuzzy operator
- Apply implication method
- Aggregate all outputs
- Defuzzify

The only steps that were not in the previous part of the work were the third and fifth steps.

Concerning the implication method, "*we must take care of the rule's weight. Every rule has a weight (a number between 0 and 1), which is applied to the number given by the antecedent. Generally this weight is 1 and so has no effect at all on the implication process.(...) Once proper weighting has been assigned to each rule, the implication method is implemented. A consequent is a fuzzy set represented by a MF, which weights appropriately the linguistic characteristics that are attributed to it.*" by Zadeh (1995, web). This weight feature can be customized in the Rule Editor interface, when setting the fuzzy rules.

Regarding the step number five, defuzzify, is the final process before getting the overall result. "*The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set*." by Zadeh (1995, web). One of the most known deffuzication methods is the centroid calculation. Such feature can be found in the FIS editor interface. There are more four built-in methods available in the fuzzy logic toolbox, besides the centroid. Besides the other options of calculation, this appears to be fast and efficient with the given results.

# Chapter 4

# 4. Summary, Conclusions and Future Research

In the end of this thesis a whole world was discover behind the warehouses walls. In a complex and exigent system, every small detail counts. These details make a warehouse capable of challenging the most demanding systems or not. Being prepared to face the most exigent clients and chains is not a quality that appears by chance. Be ready for everything requires endeavor, discipline and dedication.

This research was written to develop a new and futuristic framework of evaluation regarding the flexibility in the warehouses. The emergence of this characteristic in the actual supply chains is vital to ensure the success. In an era where the competition between partners is vulgar, being the best is mandatory.

Specifically within the warehouse's walls, being the best is not an easy feature to obtain. In this sector it is impossible to be the best in all the aspects regarding the warehouse.

Here, for example, enters a big discussion that took us throughout all the work. Compromising between flexibility and efficiency. Concerning this topic, it is impossible to be the best in efficiency terms, while being the best in flexibility aspects. The question is that all the warehouse managers have to ask for is: "What is our goal?".

Almost all the companies that achieve success in the supply chain have a clear and defined goal or aim. They are not struggling to be better than the others. They are just focusing on the most important features that could help them to achieve in the fastest and in the best way the purpose that they define in the beginning, the goal.

If by chance one of the goals will be the flexibility parameter, this paper is ideal to understand and better prepare the overall warehouse idea.

The main idea of this paper, since the beginning was to develop a system that could evaluate in a numerical way what is impossible to evaluate by numbers. In this way, what we consider immeasurable by numbers is precisely the flexibility quality in a warehouse.

This turns out to be an extensive process, since the information founded was not clear. Conjugating flexibility in production, flexibility in manufacturing and efficiency within the warehouses, it was possible to joint a large amount of factors that define the warehouse flexibility. Simultaneously, a study regarding the capabilities and advantages

of fuzzy logic took place, it is not as famous but it is a fully capable program for this framework.

Gathering all the factors described before and organizing them between the main stages through the warehouse, as Receiving, Put-a-Away, Storage, etc., it was possible to develop a program in fuzzy logic that could understand what could be difficult to analyze.

Some problems regarding the factors collections with the fuzzy logic appear.

It was difficult to restrict where the flexibility term was going. Principally when defining a barrier between flexibility and efficiency.

These two factors sometimes work in the same direction, but sometimes the opposite also happens. It is not a linear connection between them.

Another correlation that sometimes appears for the first time is logic, it is the relation between automated process, and manual process. The best balance between automated work and labor work is difficult to obtain. The relation between flexibility and efficiency enters the discussion regarding the anterior.

Concerning, the fuzzy logic program, this turn out to be easy and friendly to use, unless when facing problems with a large amount of factors, what it was in the case.

In the previous section of this paper, we analyze that it was impossible to do the work as we propose in the beginning of this thesis. Due to time consuming and software restrictions, the simplification of the framework was the only way to continue the development of the assessment framework.

A general work is never completed, and can always be improved and suffer evolutions. This one is no exception. There are some improvements that can be approached in an extension to this work. Once again, these extensions were not completed due to time restrictions.

Accordingly, we can enumerate at least two different ways to improve and get more precise results when assessing warehouse flexibility.

First, we have to realize that the software that we are using, fuzzy logic toolbox, is inserted in the main program Matlab. That is a remarkable advantage. The noticeable advantage of having fuzzy logic toolbox within Matlab is that everything we do becomes flexible. Since Matlab permits the free programming in pure coding language everything is possible. Being the limit the programmer capability. It is possible to start the program in fuzzy logic and the need of some alteration or improvements that this toolbox is not capable of doing, we can always write programming code in the Matlab to add more features to the original fuzzy logic toolbox. With this attribute it is possible to have flexibility and customization depending from what we want from the program.

In this possibility, it is also possible to enumerate some disadvantages. Fuzzy logic toolbox by Matlab has the particularity of being really friendly when developing the program. It is simple to use and not complex, being just, depending of the extension of the work, slow to develop. In contrast, pure programming in Matlab is also difficult if the user is not used to the work with this program or language. It is also time consuming and not user friendly. If we are developing an assessment tool focused in flexibility, the program itself has to be flexibility. It is easy to change in the fuzzy logic toolbox, but the same it doesn't happen in the programming language in Matlab. This is an important fact, because we will have different types of warehouses to assess and so on, some adjustments have to be done all the time. In an extensive program like the Matlab program, among hundreds or thousands lines of code, it is not easy to proceed to prompt alterations.

The second option to improve this initial work besides the programming in Matlab referred before, it is the automatic generation of rules or fuzzy rule interpolation. "*Direct application of classical fuzzy reasoning methods for complex real world tasks are facing the problem of the rule base size. One solution for avoiding the exponentially growing of rule base is the adaptation of sparse fuzzy rule-base knowledge representation and the fuzzy rule interpolation methodology.*"[Kriszán 2013, p. 1] This method is slightly different from the first approach analyzed previously. This methodology instead of covering every gap or lack of information in the program, with the lines of code written in Matlab, it does completely the opposite. This toolbox works precisely to cover gaps of information. It uses different techniques of interpolation to achieve results, even when the original program written in the fuzzy logic toolbox doesn't present enough information to get an overall result. This is due to the lack of information that normally occurs in long lists of fuzzy rules.

There are some advantages and disadvantages when applying this method. As referred to before, when facing a long problem, with a large number of fuzzy rules, this method is really efficient to apply. "*This fuzzy rule interpolation toolbox is perfect for research purpose but it is hard to use in real-time application environment.*"[Kriszán 2013,p .1] It is possible to recognize the same disadvantages as in the first option of improvement. It is not flexible as it should be, to be possible to adapt depending of warehouse type and characteristics. The results gotten with this method are close to the real ones, but not exactly the same, due to the interpolation systems.

After all, there are even more methods that it is possible to use when facing a complex problem with a large number of fuzzy rules to implement.

The decision for the best option must fall depending on the features, characteristics and proposal of each research or work. The responsibility of the work and the time available are factors that should take in account when deciding.

In the end, after all the work simplifications and reductions, and to get a more accurate result of the assessment, more experience or real time data would be needed. This lack of experience or data to best tune a company in this area that would be interested in this service could provide the program. With the experience and data provided by the partner company it would be possible to improve the evaluation program capacity.

From now on, will be possible to use fuzzy logic operations and advantages in fields where it is now was untraditional. With this it is possible to improve the way warehouses and companies work, because more important than this work is the doors opening to other areas where it can go even further.

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